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Research and Development Programs on Advanced Structural Ceramics in Korea

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[Article by Byong Sik Jeon of the National Industrial Research Institute (Korea) entitled R and D Programs of Advanced Ceramics, translated into Japanese by Masamitsu Hirano of the Mitsubishi Mining and Cement Company's Ceramics Research Institute]

[Text]

1. Introduction

With an eye on the approaching twenty-first century, the South Korean government is energetically promoting R and D in the following five areas in order to reinforce manpower engaged in high-tech [industries], develop basic science, and expand investments in technology-intensive industries:

(i) Development of technologies in electronics, data processing, and communications;

(ii) Development of fine chemicals, biomaterials, new materials (new metals, advanced ceramics, high polymers);

(iii) Innovations in conventional production technology;

(iv) Development of energy and natural resources; and

(v) Improvements in the environment and public hygiene.

Among these areas, ceramics technology, which belongs to the new materials category in (ii), has been developed since 1970. At present, the foundation of the ceramics industry is almost complete. There are presently 54 companies producing ceramics in Korea, most of them small or medium-sized companies manufacturing electronic or electrical components. However, most raw materials, except for ferrite powder, are imported. Most of the marketing of ceramics is done in the electronics industry, but it is expected that the demand for ceramics will steadily grow in ceramic engines and tools in the long run. Also, substantial investments are expected to be made in medical applications such as biotissues and the development of ceramics used in areas related to energy, data processing, and communications. Ceramics is one of the fields important in industrial innovations in the twenty-first century. It is an independent industry that will play a key role in the competition for the technological development of this nation.

Ceramics is a future-oriented technology that must keep pace with the rapid growth of high-tech industries. Hence, the demand in this field is expected

to reach $1.3 billion by the twenty-first century (a growth rate of 25 percent from $660 million in 1987, according to a survey by the Korea Industrial Research Institute [KIRI]). To be able to export to the world market, this industry is expected to reach [a business volume of] $4 billion (according to a survey by the Korea Advanced Institute of Science and Technology [KAIST]). Therefore, a great deal of effort is being put into ceramics R and D.

At present, the Korean government is investing about 2 percent of its GNP in the development of science and technology, which have grown noticeably. This investment is expected to reach 3.1 percent of the GNP by the year 2001. The government will invest $8.84 billion (14.1 percent) by 2001 in research projects to develop new materials, and plans to secure 21,000 researchers (3,200 with doctorates). To achieve this, the Materials Engineering Center will be established to play a central role in technology development. Also, a special research zone will be established to develop new materials. In view of the importance of R and D of new materials, a "Five-Year Plan for Materials Development" will be adopted from 1987 with the cooperation of government agencies, government-financed laboratories, and private-sector research organizations.

2. Current Status of the Ceramics Industry in Korea

Table 1. Research projects on advanced ceramics.

Year	Project	
1980	PZT ceramics	
1981	Gas sensors	ZnO varistors
1982	Ferrites	Nitriding of SiC
	Alumina insulators	Sintering of SiC
	PCT thermistors	
1983	Ceramic capacitors	PTC materials
	Fabricating quartz single crystals	B_4C bulletproof boards
	Ceramic diesel engines	Gas sensors
	ZnO varistors	Piezoelectric materials and ferrites
1984	Sol and gel processes	Cutting tools
	Magnetic iron oxides	Growing single crystals
	Laminated ceramic capacitors	
1985	Silicon nitride cutting tools	
	High power output capacitors	
	Fabricating single crystals	
	Piezoelectric devices	PTC, NTC
	Metallized ceramics	
1986	Insulators	Laminated capacitors
	Ceramic engine components	
	PTC registers	
	Single crystal head materials	
	O_2 gas sensors	Sound filters

2.1 Trends in R and D of Ceramics

The actual R and D of ceramics have been carried out as one of the General Research Expense Support Projects funded by the Korea Science and Engineering Foundation (KOSEF), Specific Research Development Projects supported by the Ministry of Science and Technology (MOST), or Research on Industrial Base financed by the Ministry of Commerce and Industry (MOCI). Well-organized R and D in advanced ceramics began in 1979. This topic was selected as one of the national R and D projects in 1982, and a total of about 1.6 billion won was invested in major studies of ceramics in the form of research grants and assistance until 1984. This effort is summarized in Table 1.

Ceramics research in Korea began in universities and research laboratories in the mid-seventies. Research articles published in the Journal of the Korean Ceramic Society from 1982 to 1986 are summarized in Table 2. The number of research articles have rapidly increased recently. Although γ-Fe_2O_3 is studied in universities and industrial laboratories, reports on such studies are not published.

Table 2. Ceramic research articles published in the Journal of the Korean Ceramic Society.

Topics	Number of published articles	Ratio to the total number published (%)
Mechanical functional materials	40	28
Electronic materials	93	64
Insulators	10	7
Magnetic materials	9	6
Dielectric materials	25	17
Piezoelectric materials	20	14
Semiconductors	13	9
Optical/chemical [materials]	16	11
Miscellaneous	11	8
(Single crystals, bioceramics	11	8)
Total	144	100

Reports on raw materials for ceramics and those on the synthesis of submicron-grain raw materials began to appear in 1985.

Most of the reports on electronic materials are about ferrites.

As for the research trends of publicly financed research laboratories, KAIST is pursuing various projects in government-led national research plans and those requested by private firms. Particularly noteworthy research topics among those carried out by KAIST are Al_2O_3 thick films, glass sealers, surge absorbers, sintering of SiC and Si_3N_4 ceramic cutting tools, and B_4C.

KAIST is also planning to develop hybrid IC's and silk-screen printing technology. In addition, the institute is already extensively studying single

crystals of Si and GeAs [GaAs?].

The National Industrial Research Institute (NIRI) is a government agency that handles engineering technologies and tests. Its branch laboratories provide technical guidance, analyses, tests, and research. NIRI's Ceramics Division and Institute of Ceramics Research have installed new facilities for fine ceramics and begun research on synthesis.

Synthesis of saialon [phonetic translation] using polycarbosilan [phonetic translation], $SrTiO_3$, and SiO_2 and sintering of Si_3N_4, SiC, and PZT are being carried out, and ceramic sensors and ceramic honeycombs are being studied. Also, development of metallizing techniques, synthesis of artificial gems, and research on refining techniques for high-purity raw materials are being planned.

Similarly, private-sector laboratories are aggressively participating in research. For instance, the Ssangnyong Central Research Institute is currently studying ceramic diesel engines and cutting tools. The Kumgang Research Institute has succeeded in mass producing ceramic fibers, and has developed production techniques for NTC and PTC thermistors. The Samhwa Condenser Company is engaged in the development of refining techniques for iron oxides and materials for capacitors. The Korea Tungsten Company is studying cutting tools made of Al_2O_3-ZrO_2.

Also, Sungwang Ceramic Company and Cheil Ceramic Company are studying metallizing techniques and piezoelectric materials, and other leading companies are developing insulators using Al_2O_3.

3. Domestic Market for Ceramics

The Korean ceramics industry is in a growing stage when compared with that of the United States or Japan. Ceramic electronic components are in great demand by the electronics industry. However, most of these Korean industrial facilities have been imported from abroad through technical cooperation; few have been provided through R and D by Korean research institutes or universities. With this background, the importance of ceramics as new materials has suddenly been noticed, and the Korean government recognized the need for national assistance in ceramics R and D in the late seventies.

As is shown in Table 3, more than 84 percent of the $300 million market for ceramics in 1985 was connected to the electronics industry. Only the remaining 16 percent was tied to other industries. About 35 percent of the demand was supplied domestically and the rest was imported.

In view of the recent trend in the Korean electronics industry, the potential demand for ceramics is expected to grow in the future as a consequence of a full-scale growth in semiconductor production, the automotive industry, the defense industry, and export of TV sets and VTR's.

Table 3. Korean ceramics market classified by function (1985). (Data provided by MOST)

Materials by function	Amount ($million)	Market share(%)	Import Amount($million)	Import Market share(%)
Electromagnetic				
Subtotal	240.7	81.3	145.0	73.4
Insulators	62.1	21.0	60.3	30.5
Magnetic	98.3	33.0	50.6	25.6
Dielectric	30.3	10.2	7.8	3.9
Piezoelectric	40.6	13.7	16.9	8.6
Semiconductors	9.4	3.2	9.4	4.8
Optical				
Subtotal	7.4	2.5	7.4	3.7
Mechanical				
Subtotal	6.6	2.2	3.8	1.9
Wear-resisting	3.7	1.2	0.9	0.5
Cutting tools	1.8	0.6	1.8	0.9
Abrasive	1.1	0.4	1.1	0.5
Carbon fiber, others				
Subtotal	41.4	14.0	41.4	21.0
Total	296.1	100.0	197.6	100.0
Import share (%)	100		66.7	

3.1 Electronic Ceramics

The demand for electronic ceramics in Korea began in the sixties in the form of electronic components such as capacitors, resistors, and IC's for transistor radios. Ceramic electronic components, such as insulators for resistors and ceramic capacitors, began to be produced [domestically] in the seventies when the production of black and white television sets began in earnest. As a result, many factories for electrical products were built. The Korean ceramics industry is in an initial stage when compared with those in advanced countries, but it is certain that Korea will plunge into fast paced and rough competition in the R and D of new materials among advanced countries in the near future.

(1) Ceramic insulators (Table 4)
At present, most of the ceramic IC packages [used in Korea] are imported from advanced countries such as Japan or the United States. In view of the recent trend of using multi-function, diverse, densely integrated semiconductors in electronic components, the demand for densely integrated ceramic packages such as chip carriers is expected to rise sharply.

(2) Dielectric Materials
The demand for ceramic capacitors has increased tremendously, keeping pace with the worldwide increase in demand for electronic products, and the types of capacitors are being diversified. At present, raw materials are imported in the form of semi-finished products and transformed into final products in

domestic plants.

Table 4. Demand for ceramic insulators in Korea (1984). (Data in parentheses are estimated values.)

Item	Amount produced (10^6 units)	Amount produced ($million)	Amount imported (10^6 units)	Amount imported ($million)
IC packages			426.2	60.7
Cerdips			(403.6)	(42.3)
Edge soldered packages			(15)	(12.0)
Chip carriers			(7.6)	(6.4)
Hybrid IC substrates				4.5
Thin films				(3.5)
Thick films				(1.0)
Ceramic resistor core	400	1.2		1.2
Total	400	1.2	426.2	65.2

(3) Piezoelectric Materials

Research and development of piezoelectric materials are being carried out for the domestic production of such materials because the domestic demand for them has rapidly increased owing to the fast growth of the electronics industry.

Table 5. Current status and future outlook for soft-ferrite manufacturing. (Units: $million for sales, tons/month for production) (Data provided by MOST)

Item	Source of materials	1984		1985		1990		Increase (%)	Remarks
		Sales	Production	Sales	Production	Sales	Production		
Deflection yokes, flyback transformers, El and EE cores	Japan	12.3	450	14.7	540	36.9	1400	20	TV's, radios, and home appliances
Bobbins, sleds, cup cones, peaking coils	Japan TDK	7.9	50	8.4	53	10.7	68	5	Home appliances, communication devices
Antenna bars		0.6	30	0.7	35	1.2	56	10	Radios

(4) Magnetic Materials

(i) Soft ferrites (Table 5): The soft-ferrite market in Korea is nearly monopolized by the three large manufacturers: Samhwa Electronics Company, TDK Korea, and Dae-Won Electronics Company.

(ii) Hard ferrites: The production of hard ferrites is rapidly increasing as is shown in Table 6.

Table 6. Production trends for hard ferrites. (Data provided by MOST)

Item	Products	Raw materials	1984	1985	1990	Growth rate
Hard ferrites	Speakers	Ba-Sr ferrites	520 tons/month ($118 million/ month)	574 tons/month ($129 million/ month)	922 tons/month	10 percent
	Motors, microwave ovens	Anisotropic and isotropic magnets				

(iii) Magnetic Recording Materials (Table 7): The production of VTR's rapidly increased from 150,000 units in 1983 to 1.6 million units in 1985, and that for cassette recorders reached 20 million units. This increased the domestic demand for magnetic recording materials. The demand is growing further with increased exports.

Table 7. Production trends for magnetic recording materials. (Data provided by MOST)

Item	1984 Production (1000 units)	1984 Fe_2O_3 (tons)	1984 Sales ($million)	1985 Production (1000 units)	1985 Fe_2O_3 (tons)	1985 Sales ($million)	Growth rate (%)
Video tape, total	31,245	1,504	7.52	93,735	4,500	22.5	200
Compact type	21,057	843	3.27	---	---	---	
Pancake type	10,188	622	16.19	---	---	---	
Cassette tape, total	233,881	3,883	1.09	280,667	4,600	7.52	20
Compact type	143,435	717	5.10	---	---	---	
Pancake type	90,445	3,166		---	---	---	

Since sufficient materials for magnetic heads cannot be supplied domestically, components are imported from Japan and assembled as head drums. In Korea, 3.5 million computers and 20 million audio ferrite head cores are being assembled, but most materials for these products are imported. It is essential that magnetic heads be domestically produced. (Table 8)

Table 8. Production trends for magnetic heads. (Data provided by MOST)

Items	1984 Production (1000 units)	1984 Sales ($million)	1985 Production (1000 units)	1985 Sales ($million)	Growth rate (%)
Cassette heads	1,800	0.8	4,300	9.0	20
VTR heads	590	1.0	1,600	5.5	20
Computer heads	4,850				

(5) Semiconductors

(i) Thermistors: Constant-temperature heaters for rice cookers, magnetic eraser elements for television sets, and dew-preventing heaters for VTR's are being studied in addition to basic research on PTCR for fire alarms.

(ii) Sensors: Inflammable gas alarms and oxygen sensors for steel are being commercialized. Sensor alarms for gas from coal briquettes, oxygen sensors to measure air to fuel ratios in cars and factory boilers and furnaces, and humidity sensors are being developed.

(iii) Varistors: Several companies are developing materials for ZnO varistors.

(iv) Magnetic capacitors: Development in this area is insufficient in Korea though the demand in this area is expected to grow.

3.2 Structural Ceramics

Progressive ceramics firms are carrying out R and D of structural ceramics for engines and piston rings, but the realization of such R and D is rather difficult in Korea. Only spark plugs are fabricated using raw materials imported from [Japan] NGK Insulators. Preheating plugs are in the same situation. Among other structural ceramics, mechanical seals, sand blast nozzles, insulators, capstans, spool guides, and inner linings of ball mills have been commercialized.

3.3 Bioceramics

All dental bioceramics are imported, but domestic demand for these is low at present. Only 250-360 tons of HAP (hydroxyapatite) for medical applications, as food additives, and for use in tooth pastes is imported. There are plenty of raw materials for HAP in Korea, and the need for bioceramics, such as artificial teeth and artificial bones, is still growing. In the future, domestic demand is expected to grow in dental applications, but it can be met only if problems such as economical synthesis according to applications, reasonable manufacturing costs, introduction of modern techniques, and clinical tests, are solved first.

4. Future Prospect for R and D in the Ceramics Industry in Korea

4.1 Outlook for Domestic Demands in Ceramics

In the seventies, petroleum products reflected the technological level and the international market structure of the time. In the eighties, however, petroleum products will yield their dominance to electronic products as the export of cars and state-of-the-art electronic products increases. The domestic demand for these industries was $1.36 billion in 1985 (Table 9), and is expected to reach about $2.4 billion. (According to data collected by the Korea Institute for Economics and Technology [KIET], the annual growth rate is 12.8 percent.) At this rate, [the electronics and automotive industries] are expected to grow until the year 2000 at a constant rate of 10 percent. The domestic demand for structural and functional ceramic materials will become significant after 1990. According to KIET, the demand and supply of engines in 1991 will reach $2.1 billion. Based on this prediction, the demand for electromagnetic and functional ceramic materials is likely to grow fast. The demand for fine ceramics will continue to expand to replace materials in advanced areas such as biotechnology, thermal engines, and nuclear power materials and also to respond to new demands in engines and innovations in manufacturing methods.

Table 9. Demand for electronic materials. (Unit of sales: $million) (Data provided by KIET)

Item	1985	1986	1988	1990	1986-1990 growth rate (annual average in percent)
Electronic materials, total	1,306	1,531	1,962	2,398	12.9
Semiconductors	719	893	1,265	1,588	17.2
Functional materials*	24	29	42	54	17.7
Operational materials*	9	12	17	20	17.3
Structural materials*	57	71	100	126	17.2
General component materials	587	638	697	810	6.6
Magnetic materials*	55	64	80	97	12.1
Conductors*	77	95	108	130	11.0
Piezoelectric materials*	2				
Structural materials*	200	200	244	287	7.5

* denotes ceramics

(1) Ceramics as Mechanical Components (Table 10)
At present, ceramic mechanical components are limited to cutting tools and BN abrasives, but this area is showing steady growth.

(2) Ceramics in the Electronics Industry
(i) Insulators (Table 11): The demand for ceramic insulators is for use in DIP, MLP, HIC, and ceramic cores for resistors. Aside from use in automobile spark plugs, the demand in this area will reach $2 million. In view of the growing technological cooperation with foreign firms, domestic production of IC's and packages will become a reality in the near future.

Table 10. Outlook for demand for structural ceramics. (Estimated data)

Item	Applications	Total amount ($million) 1987	1990
Cutting tools	Processing of high-performance cutting materials High-speed cutting NC machine tools	0.57	1.15
cBN abrasives	Processing of high-performance cutting materials High-speed polishing	0.57	1.15

Table 11. Outlook for demand for insulators. (Units: $million for sales, tons for production)

Item	1987 Production	1987 Sales	1990 Production	1990 Sales	Growth rate (%)
Insulators, cerdips	183.1	58.6	288.1	92.2	16.6
Multilayer packages	28.6	29.7	44.4	46.0	16.6
Hybrid IC's	50.8	40.7	87.7	70.2	20.0
Ceramic cores for resistors					
Carbon thin-film elements	30,000	5.6	42,800	8.0	12.7
Chip-type elements	1,000	10.9	1,730	18.9	20.0
Metallic thin films, other thin-film elements					
Resistors (board) for FBT Focus volume	11,000	1.5	21,500	3.0	25.0

(ii) Magnetic materials (Table 12): The demand for magnetic materials rose rapidly due to steady growth in the export of TV sets, VTR's, and micrometers. The demand is estimated to reach $151 million in 1987 and $473 million in 1990.

(iii) Dielectric materials (Table 13): Domestic needs are due mostly to disk-type dielectrics widely used in circuits for TV sets, audio devices and electric appliances. The growth rate is expected to be about 11 percent per year until 1990, reaching about $14 million.

(iv) Piezoelectric materials (Table 14): Piezoelectric materials are mainly [used in] speakers, buzzers, ceramic filters, and ignition elements. These products are expected to amount to $220 million in the form of elements and $397 million in the form of components by 1990.

(v) Ceramic semiconductor materials (Table 15): Ceramic semiconductors are mainly PTC registers, temperature sensors in NTC thermistors, oxygen sensors in automobile exhaust gas devices, industrial and home appliance humidity sensors, and circuit-protecting varistors in various electrical devices. The Demand for ceramic semiconductors is expected to reach $7.3 million by 1990.

Table 12. Outlook for demand for magnetic materials. (Units: $million for sales, tons for production) (Data provided by KIRI).

Item	1987 Production	1987 Sales	1990 Production	1990 Sales	Growth rate (%)
Magnetic materials					
Magnetic heads--Audio		1.2		16.8	11.1
--VTR		21.0		36.0	30.3
--Computer		39.8		81.8	27.1
Magnetic heads--Cassette	6.7	61.1	11.6	27.8	20.0
--Video	7.8	60.1	17.7	136.3	31.6
Hard ferrites--Communication controllers, audio devices, etc.		29.9		58.5	25.0
Soft ferrites--TV, DY, antennas, memory elements, communication equipment, etc.		59.0		115.3	25.0

Table 13. Outlook for demand for dielectric materials. (Units: $million for sales and millions of units for production) (Data provided by KIRI)

Item	1987 Production	1987 Sales	1990 Production	1990 Sales	Growth rate (%)
Dielectric materials					
disk type	6,000	48.8	820	66.7	11
trimmer type	96	6.7	131	9.2	11
Boundary layer type	600	34.9	820	47.6	11
Multilayer type	900	16.7	1,230	22.9	11
Others	91.4	1.4	27	1.9	11

Table 14. Outlook for demand for piezoelectric materials. (Units: $million for sales, millions of units for production) (Data provided by KIRI)

Item	1987 Production	1987 Sales	1990 Production	1990 Sales	Growth rate (%)
Piezoelectric materials					
Ultrasonic oscillators	70	15.82	13.8	29.2	20 (finders 20)
Audio filters	114.7	32.2	224.3	63.7	30 (buzzers 25)
Ignition elements	42.0	8.0	80.0	15.2	24
Communication equipment	159.0	56.3	306.3	200.6	25 (TV, power transducers 10)
Others	4.0	9.3	6/0	13.9	15

Table 15. Outlook for demand for ceramic semiconductor materials. (Units: $million for sales, millions of units for production)

Item	Applications	1987 Production	1987 Sales	1990 Production	1990 Sales	Growth rate (%)
Ceramic semiconductors	NTC	38.0	6.3	39.6	13.8	30
	CRT	1.0	1.2	1.3	1.6	10
	PTCR	34.0	9.4	74.7	20.7	30
	Gas sensors					
	Inflammable	0.3	0.9	0.6	1.9	30
	CO	0.6	2.4	3.5	14.1	181.3
	O_2	0.7	11.7	1.5	21.2	22.5
	IR sensors	0.3	0.9	0.6	1.9	30
	Humidity sensors	9.0	11.9	17.6	23.2	25
	Varistors	10.8	10.1	18.8	14.5	10 (Home appliances)

4.2 Long Range Research and Development Plans for Advanced Ceramics

In view of the growth of related industries, generation of new demand, and appearance of new ceramic materials, the ceramics industry will become firmly established by the nineties, but a great deal of investment in R and D is needed for that to happen. To achieve this goal through R and D, a certain amount of risk is inherent. Hence, the technology to evaluate newly developed ceramic materials is important, and such technology has been adopted as an important national project toward the twenty-first century. All tasks and stages in this project are defined in Tables 16 and 17.

Table 16. Technology for ceramic materials.

First stage (1986-1990)	Second stage (1991-1995)	Third stage (1996-2000)
Establish foundation for ceramic materials	Independent R and D in ceramic materials	Raise the level of the ceramic materials industry
Precision techniques related to ceramic materials	Expansion of R and D for applications	Research on commercialization
Advanced functional ceramic materials	Systematic, international joint research	Development plan for future generation materials
	Five percent share of the world market	Seven percent share of the world market

Table 17. Technology to fabricate and evaluate new materials.

First stage	Second stage	Third stage
Industrialization of processing technology	Settling down of processing technology	Domestic production of expensive machinery for new materials
	Establishment of foundation for evaluating technology	Completion of standardization technology

To promote ceramics, the government must provide the leadership and appeal for participation by the private sector. The government should establish a Materials Research Center and have it play a central role in the research of new materials. A Consultation Board for New Materials should be established to encourage joint research by industries, universities, and research laboratories. The commercialization of new technology will be accelerated through joint research among them. Major topics to be studied are listed in Table 18.

The outlook for R and D by industries engaged in the development of future generation ceramics is shown in Table 19. The rapid increases in research funds and personnel reflect the necessity for industrialization and growth in ceramics.

Table 19. Estimated R and D outlay by Korean industries for future generation ceramics. (Unit: percent)

Item	1975	1986	1990	Growth rate
R & D expenditure	100	122	310	25.4
Total number of engineering staff		100	740	49.2
Total number of research staff		100	300	24.5

Table 18. Major research and development topics.

Item	First stage	Second stage	Third stage
Development of advanced ceramics	Development of diesel engine components Technology to synthesize basic ceramic raw materials Insulating fibers, high thermal resistance inorganic synthesized fibers	Development of turbo chargers Development of ceramic bearings Composition of compound materials Development of bulletproof materials	Development of engine components (if possible) Mass production of ceramic bearings Development of high-strength bulletproof materials
Development of functional advanced ceramics	Fundamental research for multilayer circuit substrates Engineering applications of AM, FM ceramic filters Manufacturing technology for ceramic sensor elements Fundamental research for and applications of bioceramics materials	Technology for low-temperature thermal resistance circuit substrates Applications technology for magnetic materials Performance tests of biomaterials	Technology for nonoxide multilayer circuit substrates Development of ultrathin-film piezoelectric materials Development of crystalline magnetic heads
High-purity refinement and raw material fabrication	Synthesis of new high-purity materials Ultrafine fabrication technology High-purity refinement technology		
Technology to fabricate insulating, crystalline materials	Insulating crystal growth technology Epi-insulating crystal growth technology		
Rapid-cooled surface processing, molding, and bonding technology	Rapid-cooling technology Surface processing technology Special molding technology Special fusion technology		
Technology to analyze and evaluate materials	Separation layer analysis technology Surface analysis technology Study of material stability Study of lifetime prediction Analysis and study of causes of fractures Databank projects Technology for Precise adjustments and analyses		

5. Conclusion

Although the future of the Korean ceramics industry is bright, there are many problems it must solve. For example:

(1) Most raw materials are imported, hence it is difficult to maintain stable supply of raw materials. It is hard to secure high quality but inexpensive raw materials.

(2) Most of the Korean electronics industry assembles simple products using imported components and raw materials, thus making it very difficult to expand the market for domestically produced raw materials.

(3) The Korean ceramics industry depends on small scale production, and the market demand is also low. Hence, effective production management is difficult.

(4) It is extremely difficult to quickly predict the short-term demand for ceramics.

(5) Engineers with the broad, fundamental knowledge in fields such as materials, electronics, chemistry, and physics, required for fabricating ceramics are needed.

(6) At present, it is difficult to reduce cost by replacing existing metallic and plastic products with ceramics and mass producing them.

(7) The ceramics industry requires the most modern high technologies, such as materials synthesis and manufacturing technologies, but importing these from advanced countries is very difficult.

(8) The standardization of methods to test high-temperature strength, thermal expansion coefficients, thermal conductivity, and hardness of ceramics is necessary to improve ceramic products.

The domestic demand for ceramics in Korea is very low when compared to that in advanced countries, and the manufacturing technology for ceramics is in a developing stage. However, [the ceramics industry in Korea] must be developed according to the following methods in view of the future potential of the Korean ceramics market:

(1) Industries, the government, and universities must form an aggressive support system for the ceramics industry through cooperation. And, R and D must be actively pursued through a priority system based on medium- and long-range plans for basic and applied science projects.

(2) Superior facilities and expensive measuring devices are indispensable for developing ceramics. This requires wide-ranging financial assistance from the government.

(3) Industries, universities, and public research laboratories must conduct joint studies to activate R and D by small businesses.

(4) It is inevitable to send them abroad for education to nurture highly trained personnel.

(5) International cooperation with relevant research laboratories and ceramic industries of advanced countries is necessary to promote research in Korea.

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Ceramic Substrates for Semiconductor Applications Reported

AlN Substrates

43067524a Tokyo KINO ZAIRYO in Japanese Sep 87 pp 54-62

[Article by Katsuaki Sugimoto, Toshiba: "Ceramic Substrates for Semiconductor"]

[Excerpts] As progress continues in the field of semiconductor elements, the requirements to be met by substrates for semiconductors have been growing stricter. One of the upgraded requirements concerns thermal conductivity. Where the conventional alumina substrates cannot satisfactorily meet upgraded requirements, the needs for better substrate materials to be used instead of alumina have been rising. This paper presents a general discussion of the aluminum nitride substrates which have been put to practical use as substrates with high thermal conductivity.

1. Introduction

The thermal conductivity of an electrical insulator is determined mostly by free phonons. To obtain high thermal conductivity, an electric insulator is required to meet the following conditions[1]: 1) elements must be light; 2) elements should not differ much in atomic weight; 3) elements should be strongly bonded; 4) simple crystal structure; and 5) highly symmetrical lattice vibration.

AlN [aluminum nitride] meets the above conditions for the most part. The AlN ceramics, while having the electrical characteristics similar to those of the alumina (Al_2O_3) ceramics, the most widely used ceramics at present, feature thermal conductivity 5 to 10 times as high as that of the alumina ceramics. In addition, unlike beryllium oxide (BeO), they are free of toxicity. Therefore, they have already been put to practical use as substrates which enable the heat radiation problem to be solved for power semiconductor devices.

2. Properties of AlN, and Its Evaluation as Semiconductor Substrate

AlN is a mineral which does not exist in the natural world. It was synthesized by Genther, et al., in 1862 for the first time in the world.

The basic properties of AlN are given in Table 1.[2] AlN is a compound which has a wurtzite structure and shows strong covalent bonding. Since it excels in heat resistance and strength, it has been studied as a material for heat-resistant structural members or members which come in contact with molten metal. It has also been made known that AlN has high thermal conductivity (theoretical value[3]: 320 W/mK, actual measurement on single crystal[4]: about 250 W/mK).

Table 1. Properties of AlN[2]

Item	Value
Molecular weight	40.99
Crystal structure	Hexagonal system of wurtzite structure
Lattice constant	$a^0 = 3.1114$ Å, $c_0 = 4.9792$ Å
Specific gravity	3.261
Decomposition temperature	2,789 K
Melting point	Estimated at 3,300 K (at 10^5 bar)
Heat of formation	76 kcal/mol (298.15 K)

In the early days when AlN was producible only as a polycrystal, its thermal conductivity measured 40 to 60 W/mK at the highest. This was because, during the sintering process performed to produce polycrystalline AlN, impurities contained in the raw material turned into solid solutions in AlN particles or transformed themselves into compounds with low thermal conductivity through chemical reactions,[5] causing the thermal-conduction carriers, i.e. phonons, to be widely scattered. Recently, due to a clear understanding[6-11] of the mechanism through which AlN ceramics can obtain high thermal conductivity and development of the process for causing such a mechanism to take place as described in Section 5, AlN ceramics[10,11] with thermal conductivity as high as 260 W/mK have been announced.

Next, how AlN ceramics are currently evaluated as substrates for semiconductors will be reviewed.

Although remarkable progress has been made in the field of semiconductor devices in terms of integration density, operating speed, and output power, such progress has also caused the surfacing of various problems, including the following:

(1) Heat generation by high-density, high-output chips

(2) Signal delay occurring on high-speed chips

(3) Mismatching of thermal expansion between large chips and substrates

(4) Dielectric breakdown occurring when high voltage is used

The substrate properties that have bearing on the above mentioned problems include: 1) thermal conductivity; 2) dielectric constant; 3) thermal expansion coefficient; 4) strength; and 5) dielectric withstanding voltage.

In Figure 1,[12] AlN and other principal substrate materials are compared with alumina (Al_2O_3), which is presently the most common material for substrates for semiconductors, regarding the above properties. In the figure, substrate materials indicated at points more rightward on each property scale, except that for thermal conductivity, are evaluated more highly in respect to the property. With regard to the thermal conductivity, substrate materials indicated at points closer to where semiconductor pellet Si is indicated are less likely to cause trouble due to mismatching.

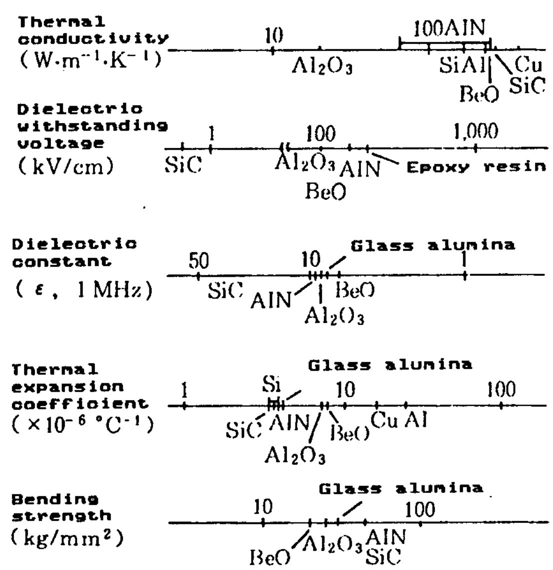

Figure 1. Properties of Various Substrate Materials Compared With Al_2O_3 [12]

As is clear from the figure, AlN has properties quite suitable for a substrate material, as follows:

(1) Thermal conductivity higher than that of alumina

(2) Electric characteristics equivalent to those of alumina

(3) Thermal expansion coefficient closer than alumina's is to that of Si

(4) Strength at least equivalent to that of alumina

Furthermore, AlN substrates can be produced using processes (such as sheet formation and atmospheric sintering) similar to those used for alumina substrate production. Powder molding is, of course, adoptable for the production of AlN substrates, so that substrates comprising multiple layers or having complicated shapes can also be made of AlN.

3. AlN Substrate Production Process

Figure 2 is a flowchart illustrating the AlN substrate production process.

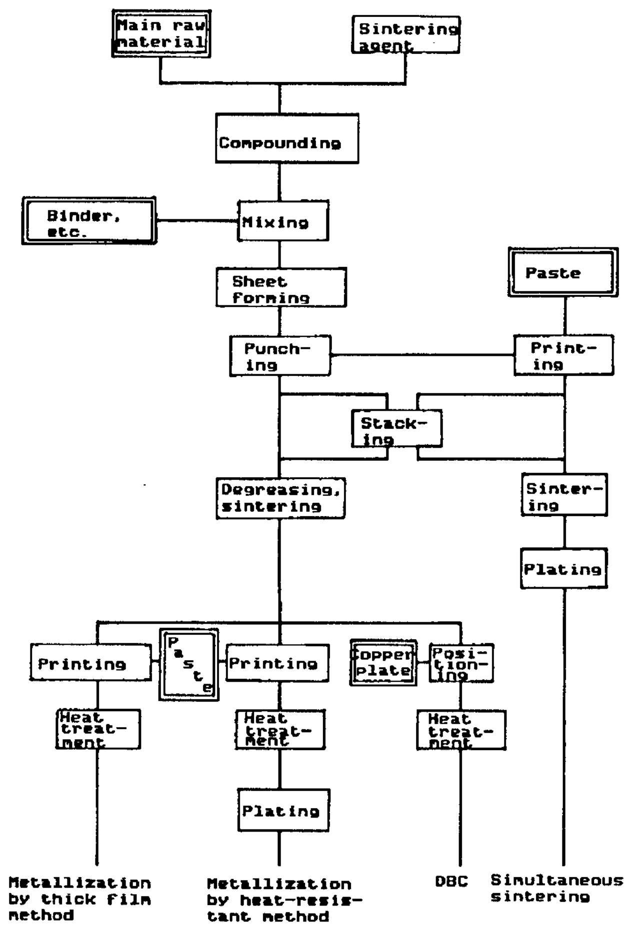

Figure 2. Flowchart of AlN Substrate Production Process

3.1 Raw Material

The main raw material for AlN substrates is, as a matter of course, aluminum nitride (AlN) powder. The AlN powder production methods include the following:

(1) Aluminum metal direct nitriding method

$$2\,Al + N_2 \rightarrow 2AlN$$

(2) Aluminum-compound carbon-reduction method

$Al_2O_3 + C + N_2 \rightarrow 2AlN + 3CO$

(3) Vapor synthesis method utilizing reactions between aluminum halides and NH_3

The commercialized AlN substrates are mostly produced by one of the first two methods. Table 2 gives the typical characteristics of different types of AlN powder which have been commercialized or are being improved following initial development by different producers.

Table 2. Characteristics of AlN Powder

Production method	Type	Particle diameter μm	Components (%) Al	N	O	Si	Fe	C
Direct nitriding method	A	4.5(1)	>64.5	>31.5	≤2.5	≤0.2	≤0.4	
	B	4.3(1)	–	33.0	0.5	0.07	0.05	0.07
	C	1.1(1)	–	32.9	2.0	0.1	0.06	–
	D	1.1(1)	–	33.2	1.1	0.035	0.01	–
	E	1.6(2)	–	33.3	1.1	46ppm	57ppm	–
Reduction method	F	0.6(3)	–	33.8	1.0	≤15ppm	≤10ppm	630ppm
	G	3.5(2)	–	–	0.04	≤90ppm	≤10ppm	≤0.1
	H	0.7(2)	–	33.3	1.5	8ppm	3ppm	0.06

(1): FSSS (2) D50 (3) SEM

Producing substrates having superior characteristics requires quality raw material. As will be discussed later, it is preferable to use a raw material which does not contain much oxygen or other impurities. The particle-size of the raw material powder is also an important factor.

3.2 Sintering Agent

AlN is known as a material which is inherently difficult to sinter. To obtain sintered AlN with high mechanical strength and high thermal conductivity, it is necessary to tightly sinter the raw-material powder. Tightly sintered AlN bodies can be obtained by heating its raw-material powder to a high temperature under high pressure. In this way, no sintering agent is required, but the process is not suitable for mass production. Therefore, to sinter AlN powder on a quantity production basis, sintering agents are used. The sinter agents in general used today comprise compounds of rare earth or alkaline earth. Such compounds have been selected based on the results of studying[6] the effects of various sintering agents on the sinterability of AlN, as well as the characteristics of AlN substrates, as will be discussed later.

3.3 Mixing and Sheet Formation

An appropriate amount of the sintering agent is added to the AlN powder, then an organic binder and plasticizer are added to the AlN and sintering agent mixture, producing slurry. The slurry undergoes a bubble removing

process in a vacuum. Next, it is molded into sheets after its viscosity has been adjusted, and the molded sheets are dried into green sheets. Subsequently, the green sheets are blanked to size, taking into account the contraction to take place during the sintering process. If necessary, they are stacked and heated in a pressurized state to produce laminated substrates. To produce prewired laminated substrates, paste made of heat-resistant metal, such as tungsten, is applied to individual green sheets using proper circuit patterns.

3.4 Degreasing and Sintering

The green sheets to be degreased are coated with a chemical in order to prevent them from melting or bonding. Next, they are stacked, and then are heated to 500-900°C in a nitrogen (N_2) gas atmosphere to remove the chemicals, such as the organic binder and plasticizer, which are no longer required. Subsequently, they are heated to 1,500-1,900°C in a nitrogen gas atmosphere to produce tightly sintered AlN sheets.

3.5 Metallization

3.5.1. Heat-resistant metal method

Applying molybdenum or tungsten paste-containing substances, which promote a reaction between the metal and AlN, to sintered AlN sheets and heating them to 1,500-1,800°C in nitrogen gas enables strong junction layers to be obtained. the metallized layers are nickel-plated for solderability enhancement.

3.5.2. Thick Film Method

For HIC (hybrid IC) fabrication, a thick film process utilizing conductive paste is employed. In the process, circuit patterns are printed on AlN ceramic substrates using appropriate types of paste, then the substrates are baked at 800-900°C to fix the printed circuit patterns.

The conductor materials used include Ag, Cu, and Au. They have a strength of about 2 kg/mm^2 which is high enough for practical purposes. Nonetheless, they cannot yet be said to have acquired adequate reliability. With regard to resistance, it must be possible to form widely ranging values of resistance with thick film. This thick film process, as a whole, has yet to secure overall reliability.

3.6 DBC®

This process is for directly joining copper to ceramic substrates. To join a copper board to an AlN substrate, the copper board is put on the pretreated surface of the substrate and is then heated to 1,060-1,080°C in a nitrogen atmosphere.

3.7 Simultaneous Sintering

In this process, circuit patterns are printed on AlN green sheets using conductive paste whose main component is tungsten or molybdenum, and the green sheets are then baked at 1,500-1,800°C in a nitrogen atmosphere to sinter the green sheets and fix the printed circuit patterns at the same time. If necessary, two or more AlN green sheets may be stacked together before baking. After baking, the printed circuit patterns may be partially plated with nickel or gold, as required, to enhance their solderability or brazability.

4. Factors in Lowering thermal Conductivity of AlN Ceramics

The thermal conductivity of AlN ceramics varies with the raw material and the production method. Generally, the thermal conductivity is considerably lower than the theoretical value. One reason for this could be that many factors affect the scattering of phonons in sintered ceramics consisting of fine crystal grains. In a poorly crystallized ceramic which, similar to the model[13] shown in Figure 3, contains strained or dislocated parts and lattice defects, phonons are widely scattered to lower the thermal conductivity of the ceramic. The scattering of phonons in a ceramic is also promoted when impurities are dissolved in AlN particles, forming a solid solution. The thermal conductivity of ceramics containing bubbles, cracks, or low thermal-conductivity second phases is also generally low. Ceramics consisting of larger grains can conduct heat more efficiently, but their grain size cannot be made larger without taking into account the corresponding detrimental effect on their mechanical properties.

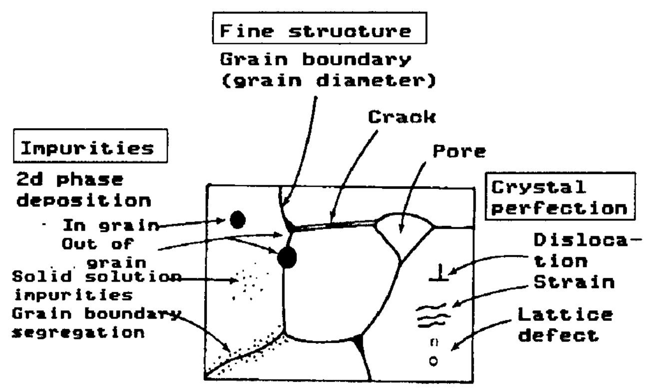

Figure 3. Factors in Lowering Thermal Conductivity of Ceramics[13]

Figure 4[14] shows the relationship between the thermal conductivities at room temperature of sintered samples prepared by hot pressing AlN powder (produced by the metal nitriding method) and the amounts of impurities, such as alumina (Al_2O_3), carbon (C), and silicon (Si), deliberately added to the powder for experimental purposes. The measurements of thermal conductivity indicated in the figure are more or less dispersed, but it can generally be said concerning all three impurities that higher impurity concentration results in lower thermal conductivity. When Al_2O_3 is added as an impurity to the AlN powder to be sintered, it allows the AlN powder

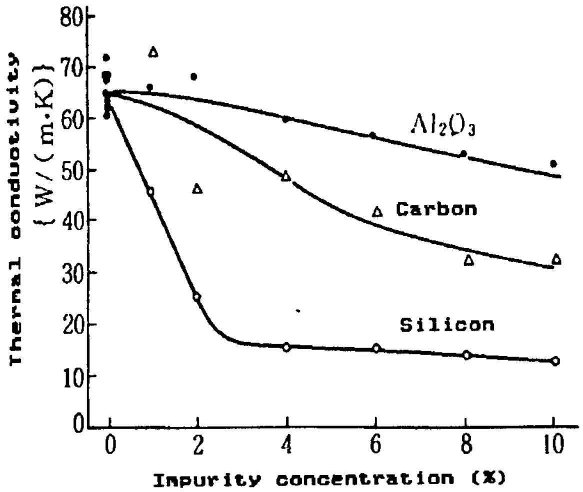

Figure 4. Relationships Between Impurity Concentrations and Thermal Conductivities of Sintered AlN[14]

to be solidified at a high density, regardless of its concentration in the AlN powder. However, its addition results in lowering the thermal conductivity of the sintered AlN because it reacts with AlN to produce aluminum acid nitride or AlN polymorphs (27R polytype phase), or causes an oxygen impurity to be fused in AlN, producing a solid solution, and eventually producing a detrimental effect on the thermal conductivity of the sintered AlN.

When Si or C is added as an impurity to AlN powder to be sintered, it allows the AlN powder to be solidified at a high density as long as its amount is not very large. Si and C added as impurities, however, are solidified in AlN to produce a solid solution or cause polytypes to be generated, lowering the thermal conductivity of the sintered AlN. If they are added in excess, they will hinder the sintering of the AlN powder.

5. Raising Thermal Conductivity of AlN Ceramics

As discussed above, the thermal conductivity of AlN ceramics is detrimentally affected by various factors. How can the detrimental effects of such factors be reduced?

Table 3[6] gives the results of measuring the density and thermal conductivity at room temperature of sintered AlN samples containing 3 wt% of different impurities. The samples were prepared by sintering AlN powder (produced by the metal nitriding method) in a nitrogen gas (N_2) atmosphere at 1,800°C under ordinary pressure. From the table, it is seen that, to obtain AlN ceramics with high thermal conductivity, it is first necessary to sinter AlN powder at a high density, and that different sintering agents (Group I in the table) added to enable AlN powder to be sintered at a high density affect the thermal conductivity of the sintered AlN to different degrees. It is for these reasons that rare earth or alkaline earth compounds have come to be commonly used as agents for AlN sintering, as mentioned in Section 3.

Table 3. Effects of Additives on Density and Thermal Conductivity of Sintered AlN[6]

	Additive	Density (g/cm^3)	Thermal conductivity ($W/m \cdot K$)
I	$CaCO_3$	3.21	75
	$SrCO_3$	3.26	55
	$BaCO_3$	3.10	60
	$CaC_2O_4 \cdot H_2O$	3.12	63
	$SrC_2O_4 \cdot H_2O$	3.19	41
	$BaC_2O_4 \cdot H_2O$	3.26	58
	Y_2O_3	3.29	72
	La_2O_3	3.33	62
	CeO_2	3.29	53
	Pr_6O_{11}	3.29	56
	Nd_2O_3	3.29	53
	Sm_2O_3	3.29	51
	Cd_2O_3	3.28	50
	Dy_2O_3	3.28	50
	NiO	3.07	42
	$Ce_2(C_2O_4)_3 \cdot 9\ H_2O$	3.30	59
II	TiO_2	2.64	18
	ZrO_2	2.84	23
	HfO_2	2.80	22
	$MnCO_3$	2.77	21
III	Li_2CO_3	2.18	5.9
	$MgCO_3$	2.31	6.0
	$MgC_2O_4 \cdot 2\ H_2O$	2.13	5.1

I Additives effective in raising AlN density and thermal conductivity
II Additives with no effect
III Additives which impede sintering and result in lowering thermal conductivity of sintered AlN

Figure 5[7] shows how the density and thermal conductivity at room temperature of AlN ceramics produced by sintering AlN powder at 1,700-1,850°C under ordinary pressure are affected by the concentration, in the range of 0 to 5 wt%, of yttria (Y_2O_3), which is considered to be the most effective rare-earth sintering agent, contained in the ceramics. The figure indicates that even only 0.5 wt% of yttria added as a sintering agent is effective in sintering AlN at high density. It is also seen from the figure that, as the Y_2O_3 concentration is raised, the thermal conductivity of the ceramic rises, though slowly, whereas the ceramic density remains about the same. Such a rise in thermal conductivity is considered attributable to the following: 1) Y_2O_3 added to AlN as a sintering agent reacts with the oxygen impurity to produce a liquid phase, then the liquid-phase sintering mechanism causes AlN to be sintered at a high density; 2) when AlN is completely sintered, Y_2O_3 is solidified as

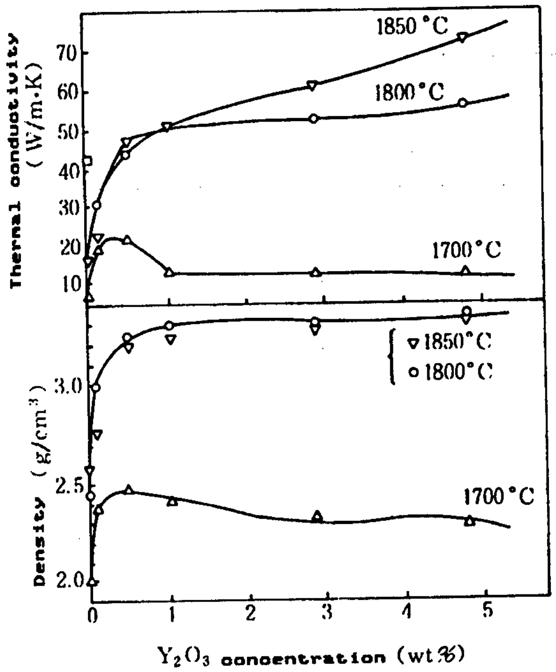

Figure 5. Density and Thermal Conductivity of AlN Ceramics Versus Concentration of Y_2O_3 Additive[7]

yttrium aluminum compounds (e.g., $3Y_2O_3 \cdot 5Al_2O_3$ and $YAlO_3$) at the edges or in the corners formed between particles, while trapping oxygen inside them without allowing the oxygen to be fused into AlN particles, and 3) other impurities are also taken into the liquid phase to make AlN particles purer, whereas the phase containing the sintering agent is deposited in a manner which does not hinder heat conduction.

Figure 6 shows the relationship between the thermal conductivities of two types of sintered AlN samples and the oxygen concentrations in the respective raw materials. One type of sample was prepared by atmospherically sintering AlN powder to which an optimal amount of Y_2O_3 had been added; the other type was prepared by hot-pressing AlN powder containing no additives. The figure indicates that the thermal conductivities of both types of samples are higher when the oxygen concentrations in them are lower. It is also seen from the figure that, when compared to the same oxygen concentration in the raw material, the thermal conductivities of samples prepared by sintering AlN powder containing the sintering agent are always higher than those of the samples prepared by hot-pressing AlN powder containing no additives. The thermal conductivities of the former type of samples produced from a raw material with a low concentration of oxygen are particularly high; the figure indicates that thermal conductivity not lower than 170 W/mK was recorded in one of these samples. This is why it was stated in Section 3 that the oxygen and impurity concentration in the AlN powder to be used as the raw material for AlN ceramics should be low. Figure 7[9] shows the mechanism by which Y_2O_3-added AlN powder is sintered, resulting in obtaining high thermal conductivity.

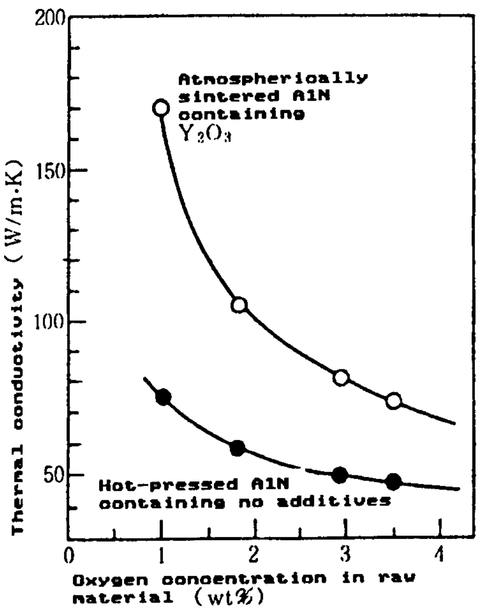

Figure 6. Oxygen Impurity Concentrations in Raw Material AlN Versus Thermal Conductivities of AlN Ceramics[8]

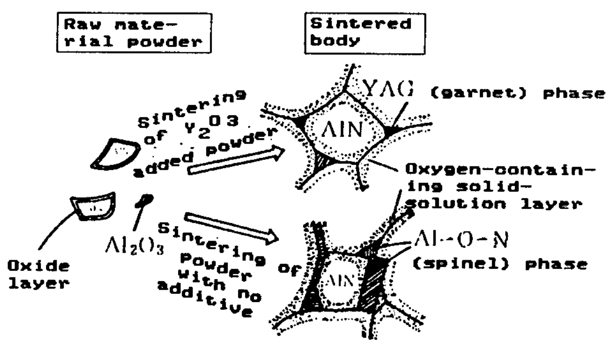

Figure 7. Mechanism by Which Y_2O_3-Added AlN Is Sintered, Resulting in Obtaining High Thermal Conductivity[9]

Efforts to raise the thermal conductivity of AlN ceramics have been made based on studies such as those discussed above. Still, 200 W/mK appears to be about the highest thermal conductivity presently achievable for AlN ceramics. Recently, however, a thermal conductivity of about 260 W/mK was reported to have been achieved as a result of closely studying the relationships among fine ceramic structure, density, and thermal conductivity.[10] Figure 8 shows the relationships observed in a test among the densities of sintered bodies of AlN, their additive concentrations, and their thermal conductivities. The test was made by sintering AlN powder (produced by the reduction method) containing 1 to 5 wt% of Y_2O_3 in a reducing atmosphere at 1,850-1,950°C. The resultant observations are as follows:

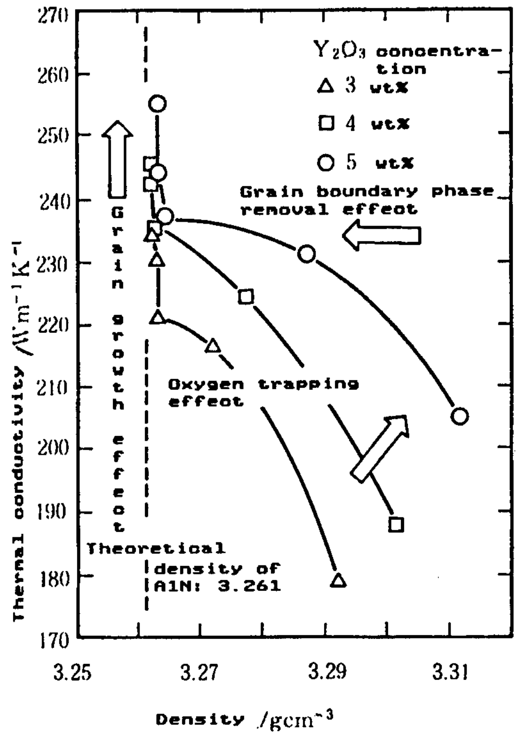

Figure 8. Sintered Body Density Vs. Thermal Conductivity[10]
(AlN sintered at 1,900°C and thermal conductivity measured at 20-22°C)

(1) Oxygen mixed in AlN powder is trapped in Y_2O_3.

(2) A grain-boundary phase elimination effect, enabling the inherent thermal conductivity of AlN particles to be obtained, is observed. As shown in Figure 9 [omitted], when the state of AlN changes from (a) to (b), the grain boundary phase reduces, while the high AlN density is maintained. In state (b), the grain boundary phase is observed very slightly around the grain boundary triple point. In state (c), the grain boundary phase is barely observed.

(3) A grain growing effect, causing the number of grain boundaries, which serve to increase thermal resistance, to be reduced, results in raising the thermal conductivity of AlN ceramics.

6. Properties of AlN Ceramics

6.1. Density

The theoretical density of AlN is, as shown in Table 1, 3.261 g/cc. The density of ceramics varies with the type and amount of additive contained. Generally, it ranges from 3.2 to 3.3 g/cc and is smaller than that (3.7 to 3.9 g/cc) of alumina.

6.2. Electric Characteristics

Table 4[15] gives the dielectric constants of AlN and Al_2O_3 ceramics at 1 MHz and 9 GHz, respectively. Those of AlN were measured by the linear line resonance method using a transmission circuit ($Z = 50\Omega$) formed by an Ag-Pd thick-film conductor on sample substrates. The sample substrates were produced by atmospherically sintering the raw materials mixed with Y_2O_3. At 1 MHz, the dielectric constants measured for the two ceramics were nearly identical. At 9 GHz, that of AlN was slightly lower than that of Al_2O_3. The value of $\tan\delta$ for AlN was about 5 - 10 x 10^{-4}.

Table 4. Dielectric Constants of AlN Substrates (at room temperature)

	Frequency	
	1 MHz	9 GHz
AlN	8.8	7.8
Al_2O_3	8.5	8.9

6.3 Coefficient of Thermal Expansion

The coefficients of thermal expansion of AlN, SiC/BeO, Al_2O_3, BeO, and Si are listed in Table 5.[16,6] The coefficient of thermal expansion (at RT to 300°C) of Si is about 3 x 10^{-6}/°C. Although the coefficient of thermal expansion of Al_2O_3 and BeO are about 7 x 10^{-6}/°C, that of AlN is as small as about 4 x 10^{-6}/°C, which is close to that of Si. From this, it is seen that the thermal stress generated when circuit elements are mounted on an AlN substrate is small and, therefore, that reliable junctions can be formed on the AlN ceramics.

Table 5. Coefficients of Thermal Expansion of Various Ceramics (x 10^{-6}/°C)

Temperature range	AlN	AlN*	SiC*	Al_2O_3*	BeO*	Si*
RT to 100°C	3.6	2.65	3.13	5.50	5.40	2.15
RT to 200°C	3.9	3.33	3.52	6.67	6.00	2.69
RT to 300°C	4.3	3.80	4.71	6.80	7.12	3.02
RT to 400°C	4.5	4.19	5.32	7.24	7.20	3.35
RT to 500°C	4.9	4.47	4.94	7.50	7.61	3.59

*According to Werdecker, et al.[16]

6.4. Thermal Resistance

To measure the thermal resistance of AlN ceramics, we fabricated sample Cerdips by mounting ICs on AlN ceramics, produced by atmospherically sintering Y_2O_3-added AlN powder and to which lead frames (made of 42 Alloy) had been soldered, covering each of them with Al_2O_3 and, finally, sealing them with glass. We then applied 0.5 W power to the samples and measured their thermal resistance.[17] The results are shown in Figure 10.

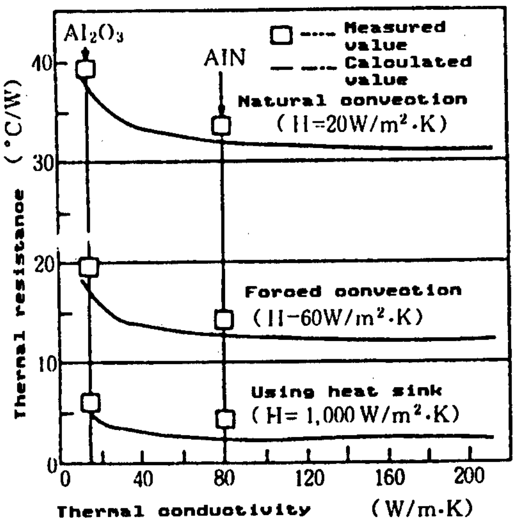

Figure 10. Thermal Conductivity Vs. Thermal Resistance of AlN and Al_2O_3 Cerdips[17]

The thermal conductivity of the AlN ceramics used in the above test was 80 W/mK; that of Al_2O_3 tested for comparative purposes was 17 W/mK. In Figure 10, the solid lines represent the thermal resistivities calculated by the approximation analysis method. It is seen from the figure that, when forced cooling by air is made, AlN permits 1.4 times larger power consumption than alumina. According to the calculation results, the higher the thermal conductivity, the lower the thermal resistance. This is particularly noticeable in the thermal conductivity range of up to about 100 W/mK.

Figure 11 [omitted] shows the results of Cerdip temperature distribution measurement made using an infrared radiation thermometer. It shows that AlN ceramics have a great advantage over Al_2O_3.

Figure 12[13] shows the results of thermal resistance measurements made on a sample while applying 20 W power. The sample consisted of an AlN substrate which had been soldered. As the figure indicates, the thermal resistance of AlN ceramics is so small that they are suitable for use as a material to make power semiconductor substrates.

6.5 Pressure Cooker Test

A pressure cooker test (PCT) was performed as a way of assessing the AlN substrate stability.

Figure 13[18] shows how the weight of an AlN substrate changes with time when kept in a water vapor atmosphere at a temperature of 121°C and under a pressure of 2 atm. As shown, the sample gains weight as time passes. This is due to boehmite (AlOOH) formation on the substrate surface. When an AlN substrate surface is covered with a boehmite layer, the boehmite layer

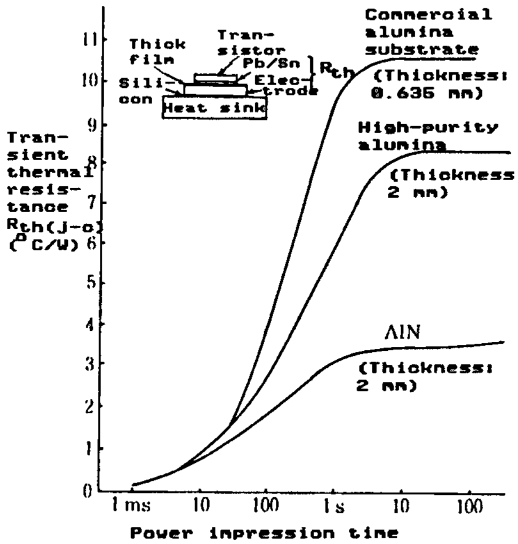

Figure 12. Thermal Resistance of AlN Substrate Carrying Power Transistor (for 20 W input power)[13]

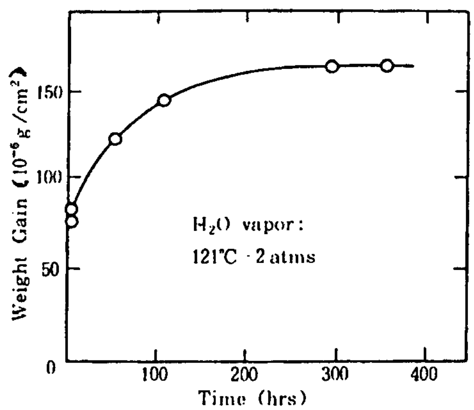

Figure 13. Results of Pressure Cooker Test Made on AlN Substrate[18]

serves to prevent the AlN from reacting further. The substrate has an insulation resistance of at least 3 x $10^{11}\Omega$ for a pair of 135 mm long electrodes arranged with 250 μm between them. Insulation resistance of that order is considered large enough for practical purposes.

7. Conclusion

Great expectations have been placed on AlN, which has superior electric, thermal, and distributive characteristics, as a material for substrates or packages for semiconductor devices. R&D on AlN is being conducted earnestly in the United States and Europe, not to mention Japan.

This paper has mainly dealt with AlN as a raw material. AlN has started being used for practical purposes. To put AlN to wider use in the future, it is necessary to improve or enhance the related material and application technologies, not to mention the fact that the further improvement of AlN itself is essential. To advance in such a direction, we intend to promote relevant R&D in cooperation with AlN users and producers of related materials.

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AlN Substrate Applications

43067524a Tokyo KINO ZAIRYO in Japanese Oct 87 pp 57-66

[Article by Nobuo Iwase of the General Laboratory, Toshiba Corp.]

[Excerpts] **1. Introduction (AlN substrate applications)**

In this paper, the author will outline the types of presently available AlN [aluminum nitride] substrates and the precautions to be taken in using them. He will also discuss in detail the factors to be considered in planning the introduction of AlN substrates and the structures, properties and merits of AlN substrates including both those already in use and those still under R&D.

It has only been 5 years since 1983, when an AlN ceramic was put to use for the first time as a semiconductor material. Since then, about 10 firms have started R&D work on AlN ceramics, and they have been promoting the work strenuously. As a result, the AlN ceramics have been greatly improved in terms of performance, centering on thermal conductivity. The number of types of AlN substrates has also been steadily growing, enabling electronic devices to be designed with greater discretion and enlarging the area in which AlN substrates can be used. But, the author believes that, because no integrated concept of AlN substrate utilization has been formed, the number of actual AlN substrate applications is still much below their latent potential. Recently, however, this situation has been rapidly changing due to such events as the development in 1986 of technologies for molybdenum metallization (by Toshiba Corp.) and simultaneous sintering,[3] and also the development in 1987 of pin-grid array package technology. In fact, some breakthroughs have been made recently for practical AlN substrate applications. The author will review the types of AlN substrates, the precautions to be taken in using them and examples of their applications. It may not necessarily be appropriate to make such a general review at this time when the situation is undergoing rapid changes, but the author's intention is to provide information useful to circuit or device designers.

2. Types of AlN Substrates

Table 1 lists various AlN substrates which are available to circuit designers or whose characteristics have been made public in academic circles or elsewhere. There may be other AlN substrates being sample-shipped or exhibited by manufacturers, but details of these AlN substrates have not been made available. The AlN substrates listed in Table 1 are generally classified according to thermal conductivity by the respective manufacturers. The manufacturers are not yet at the stage where they should classify the AlN substrates according to applications.

The general properties of the AlN substrates listed in Table 1 can be grasped based on the information included in the table. The main uses of AlN substrates and different methods of producing AlN substrates for use in different applications are listed below as information to be considered

Table 1. Characteristics of AlN Substrates

Classification	Characteristics	Toshiba					Tokuyama Soda		T D K			NEC
		TAN 060	TAN 070	TAN 130	TAN 170	TAN 200	Shapal	Super shapal	AN 100	AN 150	AN 200	
General properties	Purity (%)						> 99.6	> 99.8				
	Apparent density g/cm³	3.27	3.28				3.25			3.3		
Thermal properties	Thermal conductivity W/m·K	60	70	130	170	200	140 (RT) 130 (100°C)	260 (RT) 220 (100°C)	100	150	200	260
	Thermal expansion coefficient ppm/°C	5.7	4.6 (RT - 400°C)				4.4 (RT - 400°C)		4.5 (RT - 400°C)			4.3
	Specific heat J/g·K	0.67	0.74									
Electric characteristics	Dielectric withstanding V kV/mm	15	14				15		30	40	50	Ref 45
	Volume resistivity Ω·cm	$>10^{14}$	$>10^{14}$				$>10^{14}$		$>10^{14}$		$>10^{15}$	$>10^{13}$
	Dielectric constant @1 MHz	8.8	8.8 (8.8 @10GHz)				8.9		8.9		8.7	8.8 8.5 (9GHz
	Dielectric loss tangent @1 MHz		$5 - 10 \times 10^{-4}$				$3 - 10 \times 10^{-4}$		10×10^{-4}	5×10^{-4}	3×10^{-4}	1×10^{-4} $< 1 \times 10^{-3}$ (9G
Mechanical characteristics	Bending strength kgf/mm²	50	30				30 - 40		35			
	Young's modulus kgf/mm²	3.2×10^4	3.1×10^4				3.3×10^4		3.0		3.1	
	Poisson's ratio	0.24										
	Hardness (Vickers)						1,200		1.200			
	Fracture toughness MN/mm³ᐟ²						3.0					
Optical characteristics	Linear transmittance (%)						42 (0.5 mm thick, 6 μm wavelength light)					
	Color tone	Dark gray	Dark gray	Milky	White	White						
Nuclear	α-ray amount											
Chemical	Chemical resistance		Slightly eroded by strong alkali at high temperature									
Substrate characteristics	Surface roughness		2 - 6 μm Rmax									20 μm/20mm
	Camber, waving		Max 0.2/50mm									
Data source		Catalog					Ref *		Ref *			Ref *

*ELECTRONIC CERAMICS, November 1986 issue, p 47

when selecting AlN substrates according to various factors, including their characteristics and costs.

(1) AlN substrates in sheets produced by atmospheric sintering

--For multilayer substrates, multilayer packages (simultaneous sintering)

--For molybdenum film substrates (substrates with through-holes)

--For thin film substrates (polished)

--For DBC substrates

--For discrete-semiconductor heat sinks

(2) Press-formed AlN substrates produced by atmospheric sintering

--For molybdenum metallized substrates (post sintering)

--For thin film substrates (polished)

--For insulating heat sinks

--For flat packages

(3) Hot-pressed AlN substrates

--For insulating heat sinks

As is clear from the above, the AlN substrates can cover most of the alumina substrate applications.

3. Points To Be Observed in Using AlN Substrates

The general points to be observed in using ceramic substrates were already mentioned in Section 67 of the first installment. The points to be observed in using the AlN substrates are basically the same as those mentioned for ceramic substrates in general. In the following, the particular points to be noted when using the AlN substrates and the potential problems regarding AlN substrates will be discussed.

3.1. Etching, Plating, and Washing

The chemicals to be used for substrate washing, circuit etching and electrode plating should be given due attention. As stated in the second installment, there is no problem involving the water-resistivity of AlN substrates. The prospective users of AlN substrates should be informed of other characteristics of AlN substrates, such as their resistivity to alcohol and other organic solvents, acids, and alkalis.

Figure 1 shows the reductions in weight per unit area of AlN substrates measured after they had been dipped in different acid solutions.[7] From the figure, the relative resistance of AlN substrates to different acids can be seen.

The AlN substrates undergo weight reductions similar to those shown in Figure 1 when they are dipped in alkaline solutions. They become quite eroded when exposed to strong alkalis, such as NaOH and KOH, at a temperature of around 100°C, so any process during which they are exposed to such chemicals should be made as short as possible. They stay relatively stable when exposed to organic solvents, so it seems unnecessary to take any particular precautions against the effects on them of organic solvents.

Before conducting full-scale experiments on the etching or plating of thin-film or DBC substrates, the resistance of the substrates against the individual chemicals to be used should be examined.

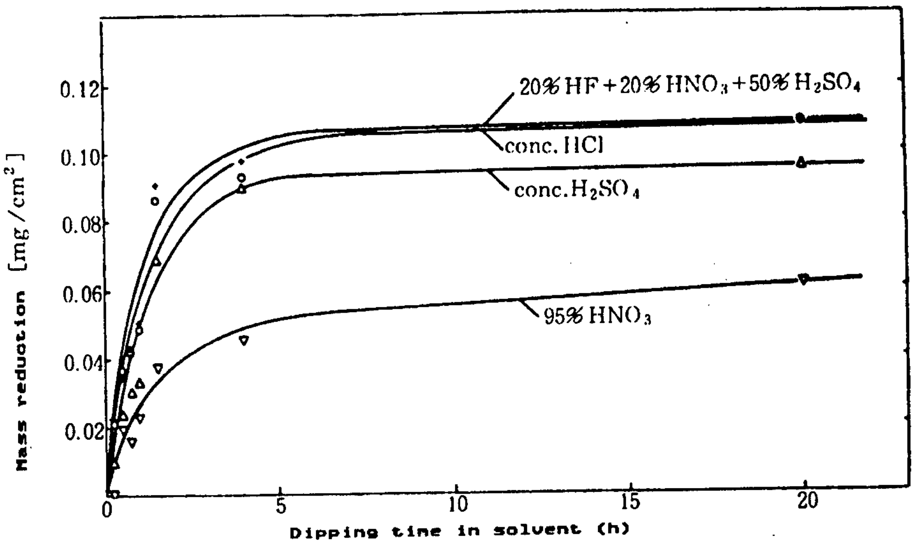

Figure 1. Acid Resistance of AlN Substrates

3.2. Laser Beam Machining (Scribing and Through-Hole Creation)

AlN has no melting point under ordinary pressure. Therefore, when it is exposed to laser energy, it sublimates directly.

For this reason it is thought that AlN can be machined by a laser more easily than alumina can. In fact, reports[2] exist on laser-beam machinability experiments in which AlN substrates surpassed alumina substrates in terms of machined verticalness, roundness, and the ratios of hole diameters on one side of each substrate to those on the other side. However, cases exist in which AlN is decomposed by laser energy, depending on the process atmosphere and the condition of the laser, resulting in reducing locally the insulation resistance of the AlN substrate. Underwater laser machining is an effective way of eliminating this problem. Other methods have also been developed to machine AlN substrates without reducing the insulation resistance of the substrates. To create through-holes in AlN substrates or to scribe them, it is necessary to determine various conditions by taking into account the type of equipment to be used and the intended use of the substrate.

2.2. Resistor Trimming

If adequate insulation resistance cannot be secured for trimmed parts of substrates, cases may arise in which it becomes virtually impossible to form required values of resistance on the substrates or in which the reliability of circuits formed on the substrates cannot be ensured. It must be remembered that cases do exist in which the insulation resistance of trimmed parts of AlN substrates is reduced for the above reason. However, it has been reported that an electric isolation strength of 100GΩ had been measured on substrates trimmed using a laser beam under proper conditions (thick-film resistor trimmed using YAG laser in air). Therefore, it is possible to achieve insulation resistance high enough, for

practical purposes, for trimmed parts of AlN substrates. To use AlN substrates, it will become necessary to determine the conditions to be met by the low-output YAG-laser trimming device to be used.

3.4 Thick Film Resistance

With regard to thick film resistance, it is not yet possible to cover as wide a resistance range as 10 Ω to 1,000 MΩ with AlN substrates. However, when the resistance range of paste to be used is limited to 1 kΩ/□ to 100 kΩ/□, AlN substrates show relatively high reliability and stability in terms of thick film resistance. When thick film pastes, originally developed for use on alumina substrates, are used on AlN substrates whose coefficients of thermal expansion are lower than those of alumina substrates, the TCR curves obtained tend to be steeper than those obtained with alumina substrates, as shown in Figure 2. For circuits which require a thick film resistance of 50 ppm/°C or less to be achieved, it is necessary to use a resistor paste developed for use on AlN.

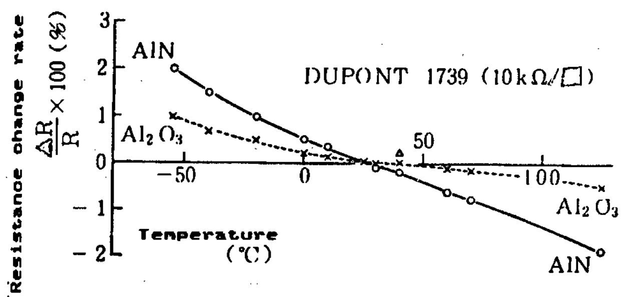

Figure 2. Sample TCR Characteristics of Thick Film Resistor, Developed for Use on Alumina Substrates, Formed on AlN Substrate

4. AlN Substrate Applications

Examples of AlN substrate applications, including those already being used for practical purposes, in experimental stages or still at research levels, will be introduced here.

4.1. Ultrahigh-Frequency Power Amplification Modules

For driver-stage or final-stage power amplifier modules to be used in compact portable transceivers or mobile radio equipment, substrates with a composite construction of beryllium oxide and alumina are used in most cases since consideration is given to both their performance and cost. In addition, beryllium oxide is expensive and toxic, and fabricating circuit boards in a composite construction involves complicated procedures. Therefore, the introduction of modules made only of AlN, which is inexpensive and free of toxicity, is being studied.

The thermal resistance of an ultrahigh-frequency transistor mounted on a 0.5-mm thick heat spreader made of beryllium oxide is 7.1°C/W, whereas that of a transistor mounted on a copper heat spreader placed on a 0.64-mm thick

(same as the circuit board thickness) AlN (70 W/m·K) substrate is 7.4°C/W, which is not very different from the above-mentioned value (Table 2). In connection with circuit configuration, the AlN dielectric constant on the VHF and UHF bands is 8.2 (inner part value), which is extremely close to that of alumina. Therefore, AlN substrates permit the same circuit patterns as those formed on alumina substrates; required adjustments can be made by slightly modifying the chips to be used.

Table 2. Thermal Resistance Comparison Between AlN and BeO

Mounting	R_{th} (j-a) (°C/W) AlN (t = 0.635 mm)	BeO (t = 0.5 mm)
With heat spreader (2 x 2.5 x 0.4 mm)	7.4	-
Direct mounting	11.9	7.1

(Pellet size: L 0.8 x W 1.62 x t 0.18 mm)

For high-frequency modules, through-holes play an important role in forming earth conductors on the circuit surface. Such through-holes can be produced with high positional accuracy using the YAG laser.

In Table 3, a sample of a power amplifier module made of AlN is compared with one made of BeO and Al_2O_3. As the table indicates, the module made of AlN is comparable to that made of beryllium oxide and alumina in terms of output power, overall efficiency, input VSWR, frequency characteristics, and input-output characteristics, so that adoption of such a module will enable the module production process to be shortened and the production cost to be reduced.

Table 3. Characteristic Comparison Between VHF-Band Power Amplifier Module Fabricated on AlN Substrate and One Fabricated on BeO/Al_2O_3 Composite Substrate

Substrate	Output power Min (W)	Overall efficiency Min (%)	Input VSWR Max
AlN	7.0	51	1.7
BeO/Al_2O_3 composite	7.3	52	1.4

Measurement conditions:		
	Frequency range:	144-148 MHz
	Collector voltage:	13.2 V
	Bias lead voltage:	5.0 V
	Input power:	150 mW

4.2. Thyristor Units for Mobile Equipment

The simplest way to use AlN substrates is as insulating heat sinks, carrying no electrode and no circuit. The first examples of these applications are found when AlN substrates are used for thyristor units or GTO invertor units. These thyristor units are constructed as shown in Figure 4,[1] in which a circular AlN substrate is press-welded between a thyristor and cooling fins. The conventional thyristor units are constructed by combining a flon gas cooler and an alumina insulator. The new type of thyristor units, containing an AlN substrate used as a heat sink, permits air-cooling. They are constructed so simply that they require no periodic inspection. In addition, they have been made smaller and lighter than the conventional thyristor units, also due to the simple construction.

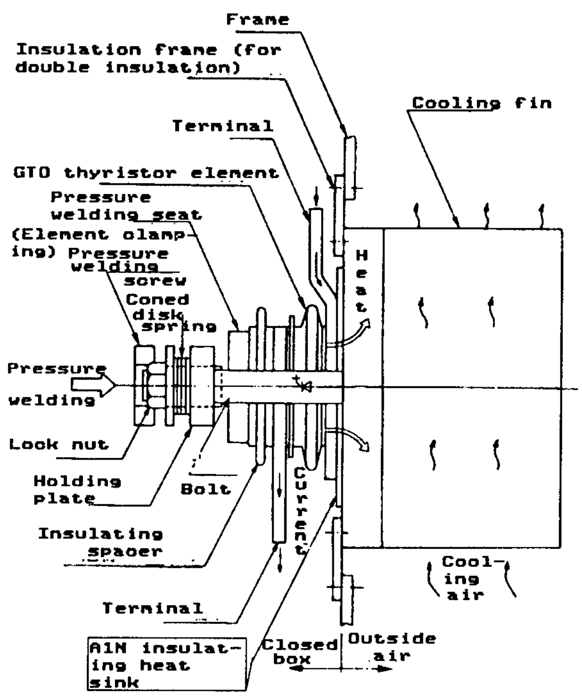

Figure 4. Construction of Mobile Thyristor Unit

The thermal flow in the new type of thyristor unit, in which an AlN substrate is used, is compared below to that in the conventional type of thyristor. It is clear that the thermal flow has been greatly simplified in the new thyristor.[4]

Conventional type of thyristor unit
(Cooled by flon gas)

(Conduction) (Boiling) (Liquid vapor)

Element ⟶ Cooling fins ⟶ Flon gas ⟶

(Refrigerant transfer) (Convection/ radiation) (Condensation)

Condenser ⟶ Air

New type of thyristor unit
(Self-cooling with air-cooling fins)

(Conduction) (Conduction) (Conduction)

Element ⟶ Conduotor ⟶ AlN substrate ⟶

(Convection/ radiation)

Fins ⟶ Air

The cooling characteristics of the new type of thyristor are shown in Figure 5. The unit will be usable for an element loss of up to about 400 W (with natural cooling). If forced cooling is used, a maximum element loss of 1 kW will be permitted.

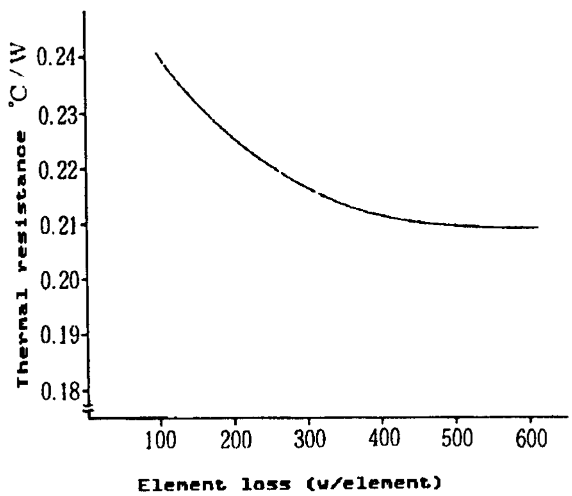

Figure 5. Cooling Characteristics of Thyristor Unit (Self-cooling type with insulating air-cooling fins)

The substrate used in the new type of thyristor unit is a hot-pressed AlN disk. Due to the high strength of AlN, the disk can withstand a large pressing force (3 tons or more) which is applied when it is press-welded in position. Such a substrate is now available with a withstand voltage of 5400 VAC or more.

4.3. Applications to LEDs for Optical Communications, Semiconductor Lasers, and High-Frequency Medium-Output Transistors

The conventional heat spreaders used in LEDs for optical communications are made of monocrystalline silicon (with a thermal conductivity of 150 W/m·K) and are covered with an electricity insulating thin film (SiO_2, Si_3N_4). Those used in semiconductor lasers are made of diamond Ia (with a thermal conductivity of 1,000 W/m·K) or silicon, and those used in high-frequency, medium-output transistors are made of beryllium oxide (with a thermal conductivity of 1,000 W/m·K).

Attempts are being made to introduce AlN substrates, which have a thermal conductivity of 160 W/m·K and both sides of which are covered with Ti/Pt/Au sputtered by the ordinary method, as heat sinks for use in the above-mentioned devices. In Table 4, measurements of the thermal resistance of semiconductor devices containing different types of heat sinks are compared.

The thermal resistance of the LED for optical communications containing an AlN heat sink is about 9 percent lower than that of the same type of LED containing a silicon heat sink. The optical output, response characteristics, and forward voltage of the former LED are approximately the same as those of the latter.

Table 4. Thermal Resistance of Various Discrete Semiconductor Devices[3]

Heat sink	92% Al_2O_3	Si crystal	AlN	99.5% BeO	Diamond (Ia)
Thermal conductivity (RT)	17 W/mK	150	160	260	1,000
Device					
Si epitaxial transistor	77°C/W	-	39	34	-
GaAlAs LED	-	95°C/W	86	-	-
InGaAsP laser diode	-	105°C/W	88	-	70

An advantage of the AlN heat sinks is that, because AlN has high heat insulation, they can be produced without requiring formation of an insulating thin film.

The thermal resistance of the semiconductor laser containing an AlN heat sink (88°/W) is also smaller than that of one containing a silicon heat sink (105°C/W). Its thermal resistance is larger than that (70°C/W) of the semiconductor laser containing a diamond heat sink, but the two are nearly identical in threshold current, optical output and forward voltage.

The high-frequency medium-output transistor containing an AlN heat sink (39°C/W) has slightly greater thermal resistance than that containing a BeO heat sink (34°C/W), and the overall loss allowable for the former is about 12 percent less than that for the latter. However, there is no significant difference between the two in respect to maximum power gain and current gain h_{FE}. In a high-temperature test (1,000 hours at 259°C, $n = 10$), the former proved to be quite stable in terms of both thermal resistance and h_{FE}, with neither property varying beyond 5 percent.

4.4. Ignition Modules

The switching sections of automobile ignition modules generate considerable heat. Substrates made of beryllium oxide, which has high thermal conductivity, or Mo, whose coefficient of thermal expansion is close to that of silicon and whose thermal conductivity is relatively high, used to be used for these ignition module sections. However, although beryllium oxide differs significantly from silicon in thermal properties, Mo presents problems, e.g., it is a conductor and is expensive.

AlN is an optimal material for use in ignition modules, not only because its coefficient of thermal expansion is close to that of silicon, but also because it has high electric insulation strength and high heat radiating ability. A feature of ignition modules in which AlN is used is a very long power ON/OFF cycle life.[6]

AlN substrates for use in ignition modules are, in many cases, Mo-metallized, enhancing their reliability at a reasonable cost.

4.5. Switching Modules

The electrodes contained in the semiconductor chips included in large-power, large-current switching modules used in various machine tools and invertor-controlled air-conditioners are required to have high heat-radiating ability. In addition, it is also necessary that their resistivity be small and their current passing area be relatively large, enabling large current flows through the circuits in which they are incorporated.

Such requirements are best met by copper. Therefore, AlN substrates for use in such switching modules are produced by the DBC (direct bond copper) method.

The AlN substrates of that type are covered with copper film, as thick as 0.2 to 0.4 mm, so that they can handle very large currents. Their peeling strength is 5 kgf/cm or more. In various reliability tests, including TCT and power cycle tests, they proved to be superior to the conventional types of AlN substrates. With their apparent coefficient of thermal expansion being close to that of single-crystal silicon, they can carry chips as large as 15 x 15 mm.

4.6. Thick-Film Hybrid Modules

The use of AlN substrates in thick-film hybrid modules is being studied, with attention focused on those modules comprising bare chips.

The modules believed to be suitable for adopting AlN substrates, with stress put on the high degree of thermal matching between AlN and silicon, include those comprising flip chips, and large chips, and those to be used in special environments.

The thick-film hybrid modules thought appropriate for AlN substrate adoption, with emphasis on their high heat-radiating ability, include those aimed at achieving enhanced module reliability, raising the maximum power allowable for resistors, or unifying power circuits with the drive-stage and control-stage circuits.

The thick-film conductor materials suitable for use with AlN substrates for such modules include Au, Cu, Ag/Pd, and Ag/Pt.

4.7. LSI Packages

The needs for smaller and faster electronic devices with more functions have been growing larger and larger. To meet such needs, larger and faster LSIs have been coming into use. Under such circumstances, the power consumption per chip is inclined to further increase for LSIs, particularly, for those containing logic circuits and, therefore, heat, radiation has been assuming increasingly greater importance for these LSIs. Furthermore, despite the progress made in integration density enhancement, chip sizes have been growing larger annually. In such a situation, the stress applied to chips when they are mounted on substrates or while they are in use has come to be regarded as a factor detrimentally affecting the reliability of the chips.

Not only does AlN have high thermal conductivity, but its coefficient of thermal expansion is very close to that of silicon, so that it is a very suitable material for packages for large LSIs. LSI packages made of AlN have been in use for the past several years.

AlN Cerdips, or flat packages having the same structure as those made of alumina, can be produced using surface-treated AlN substrates and sealing glass with a low thermal expansion coefficient. Figure 10 shows calculated as well as actually measured values of pn junction-to-ambient thermal resistance of 100-lead flat packages under various conditions. This indicates that, even though replacing alumina with AlN (80 W/m·K) results in reducing the thermal resistance by about 30 percent, little improvement can be expected in the range of higher thermal conductivity. For the diamond-touching parts and chip carriers of flat packages and Cerdips, electrodes are formed by a thick-film conductor (Au, Ag/Pt).

AlN has high thermal conductivity and can easily achieve low thermal resistance. Therefore, adopting a cavity-up structure for pin-grid array packages enables the ratio of the silicon area to be raised. Table 5 lists

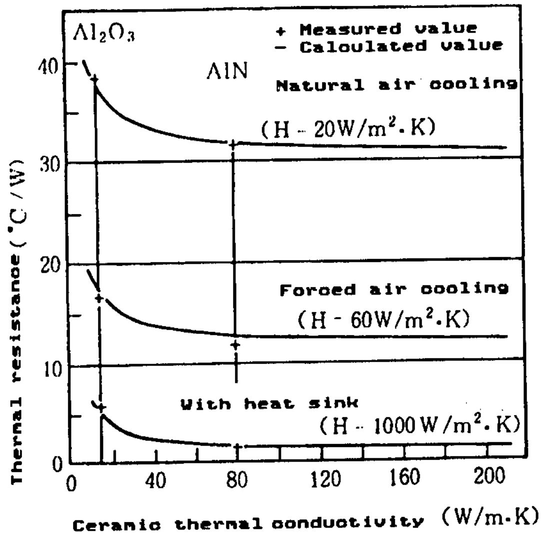

Figure 10. Relationship Between Thermal Resistance and Ceramic Thermal Conductivity of 100-Lead Flat Package (H: thermal conductivity)

the values of pn junction-to-ambient thermal resistance, measured under different conditions, of a PIN pin-grid array package comprising five simultaneously sintered conductor layers. Its minimum line width is 100 μm and minimum line pitch is 215 μm. As shown in the table, the thermal resistance of the AlN package forcibly air-cooled at 4 m/s is 3.2°C/W, which is one-fourth that of the alumina package having the same number of pins. Alumina packages with radiation fins can be replaced with thinner AlN packages having no radiation fins (natural air cooling is made).

Thermal 5. Thermal Resistance (°C/W) of 300-I/O PGA Package

Cooling condition		AlN	Al_2O_3
Without fin		17°C/W	29
With fins (20 mm high)	0 m/s	9.6	20
	4 m/s	3.2	13

(Containing □10 mm² chip)

5. Conclusion

AlN substrates have been used for practical purposes beginning only recently. AlN-applied products are expected to increase steadily from now on, centering on the fields discussed in this paper. However, AlN still requires the continuation of many studies, for example, regarding its properties affecting circuit formation and developing technology to enable its use in conjunction with other materials. Moreover, products under consideration as being suitable for adoption of AlN as the raw material require extensive prior evaluation in respect to reliability, etc. Such an evaluation will take a large amount of time. Under such circumstances, it

is difficult to predict which products are likely to be made of AlN in the future.

The properties of AlN substrates are such that the AlN substrates appear good enough to generally replace both alumina and beryllium oxide. Therefore, the development of AlN substrate applications has, so far, been focused on replacing the substrates made of these conventional materials. In the future, however, it is expected that new types of products, utilizing the features of AlN, will start to be introduced. In fact, studies of new types of AlN-applied products are already underway in some sectors. It is hoped that products exceeding the conventional standards in terms of appearance, dimensional accuracy, performance reliability and function will be developed, making use of the advantages offered by AlN ceramic substrates.

Footnotes

1. A. Tsuge, et al., Lecture texts for 1983 meeting of The Ceramic Society of Japan, pp 295-296.

2. Iwase, et al., Proc. First Microelectronics Symposium, 1985, pp 167-172.

3. Y. Kurokawa, et al., Proc. First IEEE CHMT Symposium, 1984, pp 15-22.

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6. N. Mizunoya, et al., TOSHIBA REVIEW, Vol 41 No 9, 19886, pp 811-814.

7. W. Werdecker, et al., IEEE Trans. CHMT, Vol CHMT-7 No 4, December 1984, pp 399-404.

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Ceramics-Related News Update

Vibration Compression Ceramic Forming

43067064a Tokyo CERAMICS in Japanese Jan 88 pp 69-70

[Collection of synopses of proceedings of the autumn meeting of the Powder Metallurgy Society I, 80-81 (1987)]

[Text] A research group headed by Professor Takao Nakagawa of the Tokyo University Biotechnology Laboratory has proposed a new method for efficiently manufacturing ceramic mechanical parts of complex shapes. This "water binder" method does away with the need for a lengthy degreasing process. The researchers have developed a "freeze compression forming method" in which initially a relatively large amount of water (44-55 vol %) is added to the ceramic powder, and after the mold is filled with the raw material is its immediately freeze-solidified in order to maintain the shape of the compact when and after it is released from the mold. This method has the advantage that with it parts of complex shape can be manufactured in a short time, but it was hoped that a simpler water binder method could be developed.

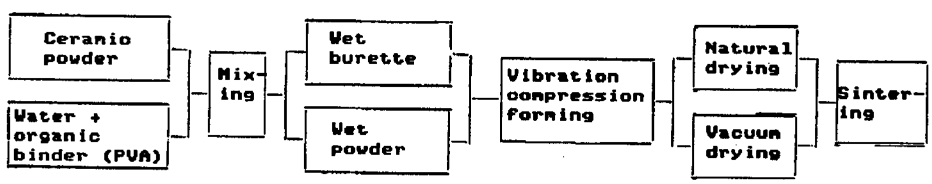

Figure 1. Vibration Compressing Forming Process With Water Binder

Figure 1 shows the process for forming ceramics by the vibration compression forming method with water binder. After the right amount of water and alumina ceramic powder (experiment done with two kinds made by Showa Denko, average particle diameter of 2 μm (AL 170) and average particle 0.6 μm (AL 160 SG3)) are mixed together, the mixture is put into the mold and pressure-formed with a vibrating punch. Although there is only a small amount of water binder in the ceramic powder, the application of vibration pressure gives it good fluidity, and as a result, the ceramic

Table 1. Optimum Vibration Compression Forming Conditions for Tested Alumina Powders

	Amplitude (mm)	Frequency (Hz)	Forming surface (kgf/cm^2)	Amount of water binder added (wt%)	(vol%)
AL-170 (dispersed type)	2	25-30	600-700	8-9	25-28
AL-160 SG-3 (uniform type)	2	25-30	500-600	12-13	35-37

powder is densely packed in the mold, and the compact which results maintains its shape and is easily separated from the mold. The compact can be rapidly dried by vacuum drying because it contains only a very small amount of water binder. Professor Nakagawa's group, while seeking to improve fluidity by repeated vibration, which was proposed as a means for achieving uniform density, developed a process for making high-density compacts of complex shapes with less water added. To discover the optimum forming conditions, they studied the effects of applying vibration with various frequencies (0-60 Hz) and amplitudes (9-10 mm) of oscillation. They found that just by repeatedly applying vibration to the punch as shown in Table 1, the density of the compact was greatly increased and very good fluidity was obtained. They infer that repeated vibration doubles the thixotropy in the presence of a liquid binder. It was learned that there are optimum frequencies and amplitudes for "vibration compression forming" and that they can easily be obtained with existing vibration generator systems. Using the vibration compression forming method with added water, an alumina compact can be formed with an extremely thin side wall of 1.5 mm, which is not achievable with existing compression forming methods or with the compression forming method using water binder.

Temperature Extraction Forming

43067064a Tokyo CERAMICS in Japanese Jan 88 p 70

[Collection of synopses of proceedings of the FY 1987 meeting of the Powder Metallurgy Society II, 66-67]

[Text] A research group headed by Toshihiko Nishida, a lecturer on the Industrial Chemistry Faculty of the Industrial Arts Department of Kyoto University of Industrial Art and Textile has developed technology for quickly and simultaneously performing both forming and sintering by extrusion molding of raw material powder in a high temperature range which allows sintering. The technology is on its way to being applied to forming Ba-Y-Cu-O compact wire. In the experiment, commercial $BaCO_3$, Y_2O_3, and CuO were mixed together in the proper proportions to form $Ba_2YCu_3O_7$ and then crushed in a ball mill for 24 hours using methanol as a medium. The resulting mixed powder was provisionally molded, then provisionally baked for 2 hours at 950°C, and crushed again by the same means as before, yielding the raw material powder. Next, this powder is filled (burette)

into copper containers at a pressure of about 500 kg/cm^2. The burette is put into an electric furnace and kept at 800-1,000°C and preheated for about 5 minutes, then immediately moved to a pressure-resistant container and extruded with a press (inside diameter 25 mm, die holes of 10, 12.5, and 15 mm in diameter). There is a gap of about 1 mm between the burette and the container, and the burette is first pressed fully in the container. When the stroke is further advanced, part of the tips extruded and the load simultaneously decreases somewhat. But since the cooling of the burette is quite fast, the load tends to unilaterally rise as the extrusion proceeds. The material adhering to the surface of the burette after extrusion is the glass and BN powder used for lubrication between the burette and the container. The researchers think lower-load extrusion will be possible by suitably choosing the composition of the lubricant and by taking steps to prevent lowering of the temperature of the burette during extrusion. To obtain multicore filament, experiments were also conducted for extrusion processing treatment for burettes with many small-diameter holes, but it proved difficult to fill small-diameter holes uniformly with compact powder. On the other hand, although the cross-section tended to be nonuniform, it was confirmed that a multicore structure can be done by the same method. Mr Nishida says this process is a very fast high-pressure technology and believes it can be used for giving the extruded compacts higher density. When a cross-section of the extruded BaYCuO compact was actually polished and the variation in its Vickers hardness was examined from its core to its outer perimeter, it was found that the center part tended to be softer. But these values are higher than those (water absorption 2.27 percent, H_V = 2,750) of a sintered body obtained by separately molding raw-material powder and baking it for 30 minutes at 900°C, and it was found that somewhat higher density was achieved.

Computer Controlled Testing Equipment

43067064a Tokyo CERAMICS in Japanese Jan 88 p 77

[Text] The National Research Institute for Metals of the Science and Technology Agency has developed computer controlled testing equipment. The testing equipment can determine accurately the relationship between the dynamic properties of a material and its processing conditions by combining any thermal conditions such as heating and cooling with any mechanical conditions such as stress and strain in a high vacuum or in an inert atmosphere such as argon gas. Its main testing jigs are made of fine compacts, and a high-frequency heating and gas rapid cooling system makes it possible to heat to a temperature of 1,800 K. Its maximum load capacity is 620 kN, and its testing speed is variable from 1 μm/sec to 0.2 m/sec. So-called hard-to-work materials such as metal-metal compounds and compacts, which are seen as heat-resistant materials of the future, cannot be molded without strictly controlling the thermal and mechanical conditions. If, in addition, a precisely controlled microscopic structure can be achieved by such processing, it is likely that materials with new physical properties can be created. Thus, this equipment is being used to study the high-temperature workability of Ti-Al based light-weight heat-resistant metal-metal compounds and the dynamic properties at room temperature of materials whose structure is controlled by the processing.

13278/9365

All Research Articles in Jan 88 Edition of National Aerospace Lab News

Basic Research in Supersonic Combustion

43062055a Tokyo KOGIKEN NYUSU in Japanese Jan 88 pp 2-4

[Article by the Prime Mover Department, Aircraft Pollution Research Group]

[Excerpt] As seen in the NASP project in America and the SP project in Japan, there has been a strong demand in recent years for supersonic combustion technology using air as an oxidant for horizontal take-off ultrasupersonic aircraft. Flight at Mach 6 or faster generally uses a scramjet (supersonic combustion ramjet) engine, which sucks in air and uses hydrogen fuel. The chief performance demands required of its combustion chamber are that ignition and a stable flame be maintained when fuel is injected into the mainflow of air, and that the combustion time be shortened by promoting better mixing. The speed of combustion is determined by the diffusion mixing of the fuel and by the type of fuel injection and shape of the burner. For ignition and flame maintenance the temperature and pressure at the combustion chamber intake are important, and so is the formation of the mixed air. Many detailed analyses have been made concerning the phenomenon of mixing diffusion caused by the injection of fuel into an ordinary subsonic flow, but it is difficult to determine its optimum diffusion mechanism because with a supersonic flow this is associated with a complex shock structure due to fuel injection and simultaneously strong interference with the air. This has motivated much of the research carried out in fuel injection and combustion methods since the 1960s in the United States, mainly at NASA's Langley center. From this standpoint, the present research focuses on the process of mixing fuel and air, which is a key factor affecting performance in supersonic combustion. It seeks to elucidate this phenomenon by making use of laser measurement and numerical calculation, in which considerable technology has been developed. The ultimate goal of the research is to explain the mechanism by which supersonic combustion operates and to obtain the basic support data needed for designing stable, efficient combustion methods. This research begins by using laser schlieren to make a two-dimensional visualization of the flow when hot air simulating fuel is injected into the mainflow moving at M=2, and macroscopic observations are made by simultaneously measuring the static pressure distribution on the wall.

In the first experiment, a two-dimensional model of right-angle effusion having a slot nozzle (1 mm wide) in a channel of rectangular-shaped cross-section (about 50 mm^2) was attached to a normal pressure line on our

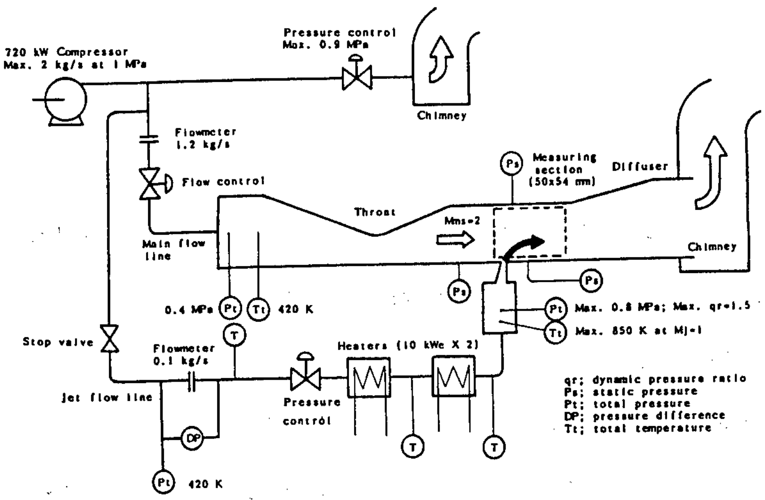

Figure 1. Construction of Supersonic Mixing Test

high-pressure combustion testing equipment. As shown in Figure 1, air from a 720-kw compressor is divided into two systems. One forms the Mach 2 mainflow with a total intake pressure of 4 ata, and the other forms a high-temperature sonic-speed jet after passing through electric heaters (10 kw x 2). The effusion temperature (total temperature about 850 K) and the dynamic pressure ratio ($q_r = \rho_j u_j^2/\rho_m u_m^2$, equal to about 1.5) of the jet to the mainflow are chosen for the operating parameters of the jet. Quartz glass for laser measurement is on each end of the effusion block, and on the lower wall and upper wall of the block are the necessary number of static pressure measurement holes. In the laser schlieren observation experiment the beam from a 4-W argon laser (light source) is spread and reflected in the parabolic mirrors (D=200 mm, F=2,000 mm) on both sides of the effusion measurement unit. The resulting image which is projected on a screen is recorded by a video camera.

Figure 3 shows the schlieren photographs and the wall pressure distribution when a jet is blown from the slot into the Mach-2 mainflow. In the case of a subsonic jet (diagram, left) there is weak oblique shock on both sides of the jet flow, and no great change is seen in the wall pressure distribution. But when the jet is at sonic speed (diagram, right), the structure of the flow generally becomes complicated, with separation shock arising from the upper flow boundary layer on the bottom wall, bow shock in the upstream jet, and reattachment shock downstream. In addition, there is reflection shock on the upper wall due to the strong blocking at the time of effusion. What is characteristic is the Mach disk due to underexpansion of the jet and the formation of a small recirculation flow area immediately upstream and downstream of the base of the jet. Regarding the behavior of the jet behind the Mach disk, it is inferred that a change in density arises in connection with the strong mixing with the mainflow. Local measurement by laser instrumentation using CARS or LDV is needed to explain

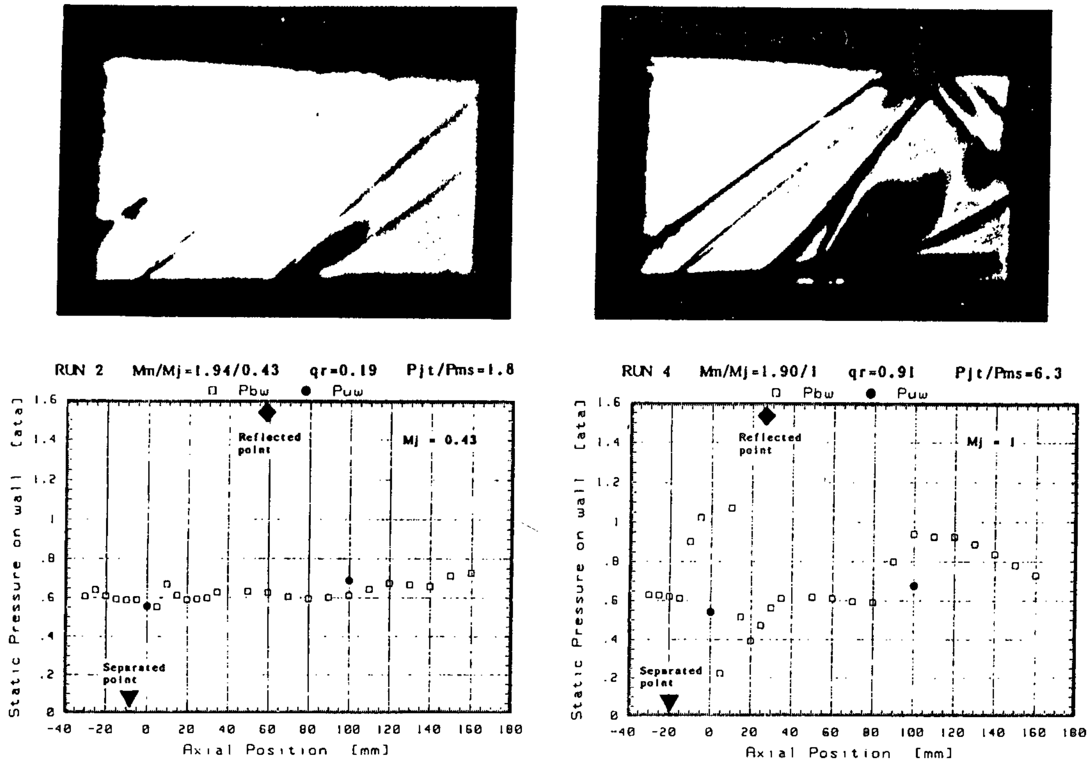

Figure 3. Schlieren Photographs and Distribution of Static Pressure Distribution

these detailed phenomenon. Likewise in the wall pressure distribution (diagram, lower left) there is an increase in pressure in the upstream part of the effusion, considerable change in pressure immediately behind the jet, and an increase in pressure due to reflection shock. One characteristic of a two-dimensional slot jet is that overshoot is observed in the wall static pressure immediately behind the jet.

Next, Figure 4 shows a plot of the changes in the dynamic pressure ratio q_r for various positions of the separation points of the upstream boundary layer on the bottom wall and the reflection points on the upper wall in the case of sonic-speed effusion. Both the separation points and the reflection points more upstream as q_r increases, and as q_r reaches 1.5 or more, normal shock arises due to strong interference between the mainflow and the jet, and at the same time the Mach number of the mainflow decreases and it becomes an unstable intermediate flow. The parameters which affect self-ignition and flame maintenance in an actual supersonic burner are the size of the recirculation region caused by upstream separation, and the mixing ratio, static temperature, and static pressure there; one of the factors thought to determine these is the dynamic ratio q_r. As stated above, the mixing mechanism associated with the effusion of fuel into a supersonic stream includes a complex shock configuration, and the heat generated by the combustion reaction causes thermal shock and makes the situation even more complex. At present we are analyzing the data for the

local temperature distribution around the jet which was obtained with the sample CARS thermometer we developed (see KOGIKEN NYUSU No 236), concentrating on hot/cold mixing between the mainflow and the jet.

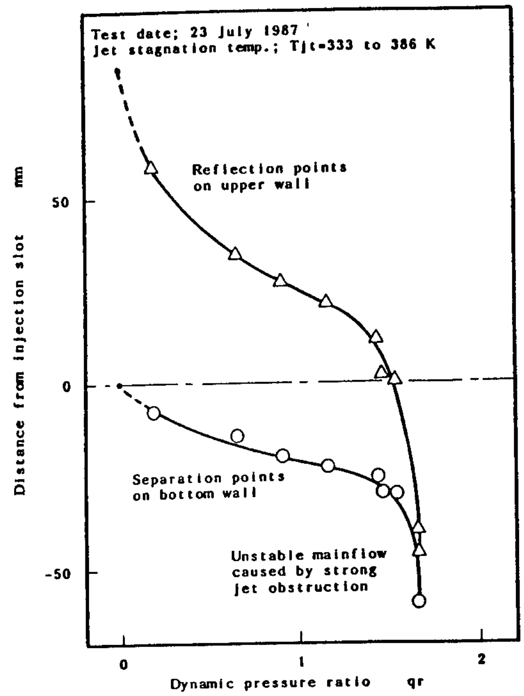

Figure 4. Change of Position of Boundary Layer Separation and of Shock Wave Reflection

This research is part of the Research Into Air-Breathing Engines for High-Speed Craft (see KOGIKEN NYUSU No 338) and is being carried out in mutual cooperation with the Scramjet Combustion Chamber Research being carried out at the Tsunoda Branch Lab (see KOGIKEN NYUSU No 331).

Aerodynamic Analysis of Natural Laminar Flow Airfoil

43062055a Tokyo KOGIKEN NYUSU in Japanese Jan 88 pp 5, 6

[Article by N. Kawai and N. Hirose, Aerodynamics Department No 2]

[Text] Research into technology for laminar flow wings to greatly reduce aerodynamic frictional drag is being carried out as part of the research and development effort for innovative aviation technology to dramatically improve the performance of aircraft. Generally, aerodynamic frictional drag is greatly reduced by making the boundary layer a laminar flow. Making it laminar by entrainment is a technique of laminar flow control, while making it laminar by modifying the pressure distribution is a technique of natural laminar flow. Combining both techniques is considered practical, but here we discuss numerical analysis of natural laminar flow.

Using methods of computational aerodynamics, we analyze the aerodynamic characteristics of natural laminar flow airfoils. Specifically, using the beam-warming method we do a numerical analysis of the Navier-Stokes equation and use a Baldwin-Lomax turbulence mode. The transition determination is modeled by empirical rules; that is, we use and compare both the widely used Baldwin-Lomax determination method and Michel's determination method, which is highly rated for transition determination of low-speed flow.

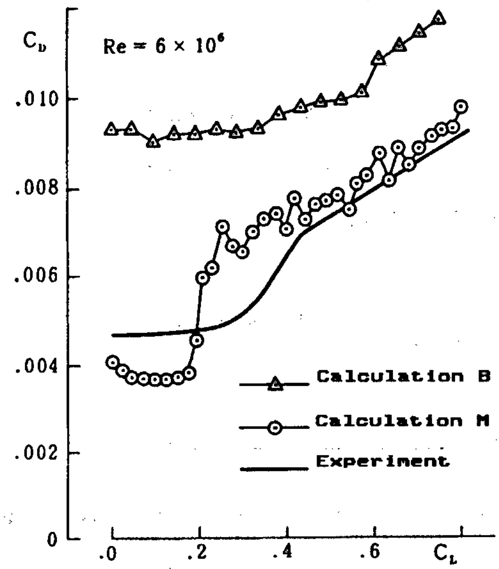

Figure 1. Calculated Values and Experimental Values for Drag Coefficient of Airfoil NACA 64_2-015

First, to evaluate the analysis method and the transition determination method, Figure 1 compares the calculated values and the experimental values (taken from "Theory of Wing Sections") of the drag coefficient of the NACA 64_2-015 airfoil, which is known as a laminar flow airfoil at low speed. The drag coefficient based on the transition determination method of Baldwin and others (shown with triangles) is considerably higher than the experimental values (solid line), and the bucket properties characteristic of laminar airfoils are not seen. On the other hand, the drag coefficient based on Michel's determination method (shown with circles) agrees well with the experimental values as long as $C_L > 0.4$. In this range the transition points on the upper surface are near the leading edge. When $C_L < 0.2$, it is noteworthy that the bucket properties characteristic of laminar flow airfoils are calculated because the laminar flow region on the upper and lower surfaces is larger. However, there is a discrepancy between the experimental values and the lift coefficient at the bucket boundary, and although the quantitative evaluation is still not complete, it is shown that Michel's transition determination method is the better one.

Next, from the practical standpoint, an analysis in the case of transonic speed and a high Reynold's number was done, and the results are shown in

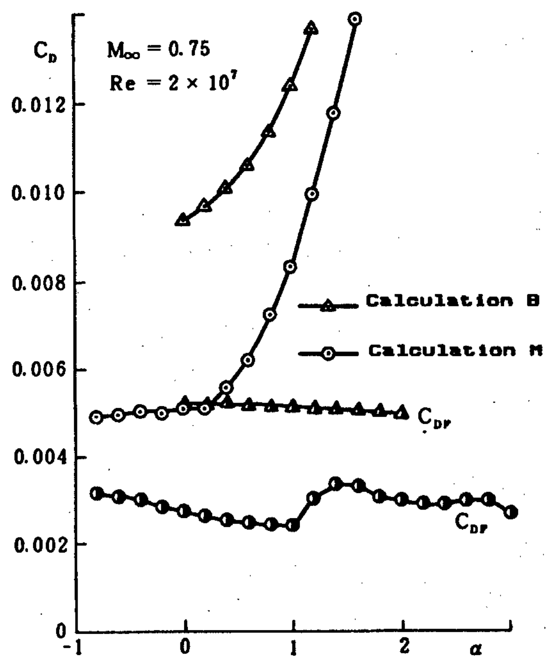

Figure 2. Calculated Drag Coefficient Values for Transonic Laminar Flow Airfoil 75-60-12(003)

Figure 2. The airfoil used was the experimental transonic natural laminar flow airfoil 75-60-12(003) designed by the New-type Aircraft Research Group. Calculation by the transition determination method of Baldwin and others (shown with triangles) yields a high drag coefficient. Here, although it is a transonic laminar airfoil, the transition points are near the leading edge for both the upper and lower surface. On the other hand, calculation by Michel's transition determination method (shown with circles) yields a quite low drag coefficient. Here, as predicted by the airfoil design, the laminar flow region is quite large on both upper and lower surface ($\alpha \leq 1.0°$). This diagram also shows the drag coefficient C_{DF} based on friction, but it suggests that the difference with the total drag coefficient CD is not just a difference with C_{DF} but that because the boundary layer gets thin, there is a small contribution from the drag coefficient based on pressure.

As a conclusion, the Baldwin-Lomax transition determination method cannot be used for the analysis of the properties of natural laminar flow because it overestimates the transition toward the front, making the drag coefficient too high. On the other hand, Navier-Stokes analysis using Michel's transition determination method can be used for drag properties including natural laminar flow with accuracy good enough that it agrees quite well with experimental values, at least for low speeds; even at transonic speed, a solution can be calculated which asserts the presence of

a natural laminar flow, and it agrees with the prediction of the airfoil design.

Navier-Stokes analysis has tended to focus just on establishing numerical analysis techniques, but in the future more attention will be given to research in its original purpose, the evaluation of aerodynamic properties.

Research on Fractography of Heat-Resistant Alloys

43062055a Tokyo KOGIKEN NYUSU in Japanese Jan 88 pp 6-8

[Article by H. Terada, Fuselage Department No 2]

[Text] With the progress made in fracture dynamics, the concept of admissible damage has become a part of designing aircraft fuselages and systems in order to achieve lighter weight while increasing aircraft safety. As basic research to apply to engine structures this concept which allows a certain amount of crack defects, our Fuselage Department No 2 is conducting research on fracture toughness and experimental research concerning fatigue crack propagation behavior of materials for engine rotor disks under actual extreme conditions.

In this paper we report the results of fractography research by electronic microscope concerning fracture of samples gained through such testing now being carried out. It is well known that fractures provide many clues concerning the environment and the size and frequency of the load that led to the breakage of a structural member, so that observation of fractures is useful in determining the cause of an accident. Study of fractures is also important as a way to determine their mechanism from the standpoint of preventing fracturing in structures.

The materials used in the tests were titanium alloy (Ti-6Al-2Si-4Zr-2Mo) for compressor disks and two types of nickel-based alloy (Inconel 718 and Waspaloy) for high-temperature turbine disks. For comparison purposes observations were also made for general-use rolled steel plate SS-41.

Figure 1 shows the results of the behavior of the progress of the cracking observed macroscopically and the results of observing the striation spacing microscopically, compared at various temperatures. If both were equal, the measured results would lie along the 45-degree straight line, but it is clear from the diagram that in the region of slow crack propagation speed the striation spacing is greater than the macroscopically observed value, and in the region of fast crack propagation speed it is less; they are in a 1:1 ratio where the striation spacing falls in the relatively narrow range 0.3-1 μ. This can be explained by the difference in crack propagation mechanism between the region where the crack is short and develops slowly and the region where the crack is long and develops rapidly.

This research was carried out for 6 months beginning in April of last year at the Fuselage Strength Research Office of Fuselage Department No 2 with the cooperation of Shigeru Omachi of the Forensic Lab of the Metropolitan Police Office, who was sent for research and training.

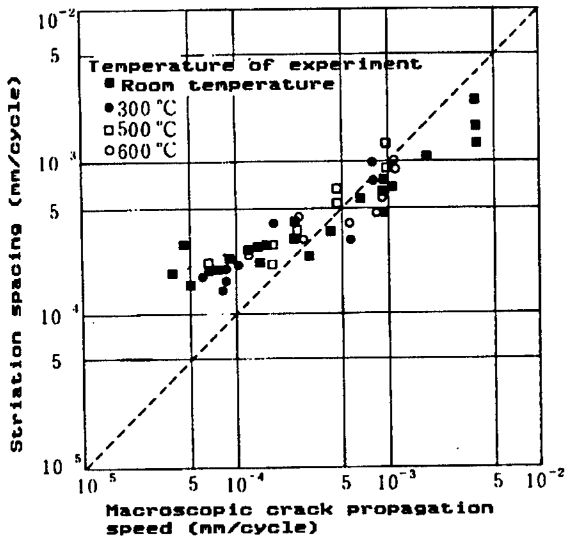

Figure 1. Relationship Between Macroscopic Crack Propagation Speed and Striation

Application of AI to Space Systems

43062055a Tokyo KOGIKEN NYUSU in Japanese Jan 88 pp 8-10

[Article by the Mathematical Analysis Department Data Processing Laboratory]

[Text] The space station and other projects being developed through international cooperation with Japanese participation involve the construction of space laboratories as a platform for various kinds of space experiments, such as experiments to create new materials using the space environment of weightlessness and vacuum, life science experiments, and observation experiments. The diverse, complex, and long-term experiments done in a space laboratory will be actually carried out by a small crew of passenger-scientists (PSs). This means that most experiments will be carried out by a crew member who is not a specialist in the experiment's subject matter, and the scientist directing the space experiment (PI) will be on the ground. In performing the experiments, the crew will have to 1) learn the individual procedures of each experiment and understand the intent of the experiment, 2) carry out and monitor multiple experiments in parallel, 3) diagnose and repair any breakdowns in equipment used for the experiments, and 4) prepare a schedule for many experiments. Thus, the operational burdens on those performing the experiments will be greatly increased, making it very difficult to smoothly run experiments in the usual way. Experiment control and support from the ground may also become too complex, lengthy, and burdensome.

Thus, in carrying out space experiments it is necessary to make the crew's work in the space lab and the control and support from the ground more autonomous and intelligent, and to establish technology for running these experiments smoothly and efficiently.

With this in mind, since FY 1968 the National Aerospace Lab, as part of its Research for Experiment Technology Using the Space Environment (Special Research), has been conducting research into space experiment support expert systems using artificial intelligence technology (knowledge processing technology). Such systems can complement and take over part of the intellectual work of the PSs and other crew in a laboratory in space.

Below we outline two prototype expert systems which have been developed as the main components of a space experiment support expert system.

Outline of Electronic Manual System

Space experiments will involve PSs and other crew members carrying out dozens to hundreds of experiments during a 90- to 180-day stay in the space laboratory. This will make the experiment manual very large, representing the PS with a considerable burden in understanding it and using it for reference. An electronic manual system could put an immense manual into an easy-to-look-up database form which would make it possible to easily get an overview of the individual experiments, look up any experimental procedure, and obtain an explanation of the terminology and concepts peculiar to an experiment. For this research we chose as an example a sound wave levitation experiment called "elucidation of the behavior of bubbles in a field where there is a temperature gradient and supersonic standing waves." It was selected from the Shuttle primary materials experiment (FMPT), involves a PI at the National Aerospace Lab, and is thought to place a heavy burden on the PS who must perform the experiment.

1) Functional outline: Guidance is given for the procedures of the experiment. At each step, in response to questions detailed explanations are given concerning the purpose and principles of the experiment, the nomenclature of the equipment, technical terminology, and the operations that are required. Instructions are given for what to do in the event of unforeseen circumstances such as obstacles (Figure 1).

2) Knowledge base: Each instruction recorded in the experiment manual is analyzed, broken down on the terminology level, and organized according to individual names (meanings, places) and actions (meanings, methods, purposes, matters to check, what to do if something goes wrong). A detailed reworking was done for matters hard to understand as written. The knowledge is classified into that which concerns the procedures of the experiments and that which concerns terminology. The former are presented as IF-THEN-type rule-based knowledge and the latter as frame-based knowledge in a hierarchical structure.

3) Computer environment: Mainly ESHELL on a FACOM 780, along with UTILISP.

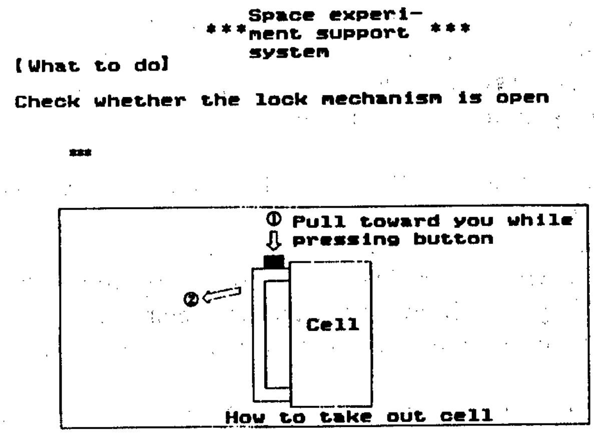

Figure 1. Example of Electronic Manual System Procedure Guidance

Outline of Experiment Scheduling System

Extremely limited resources (e.g., the PSs' work time, electric power, telecommunications rates, quantity of fluids, etc.) are available for experiments in space. The PS must flexibly draw up and modify the experiment plan in accord with changing conditions so that as many experiments as possible can be carried out efficiently and flexibly in coordination with the resource plan for the entire space laboratory. This requires an experiment scheduling system to help in planning experiments. The role of the experiment scheduling system is to show what kind of schedule an experiment should be performed on in order to accomplish it within the predefined resource constraints.

In our research we used data for 17 materials-related experiment models, mainly experiment models for the space station Japan experiment module.

1) Function outline: The optimum experiment schedule is drawn up and graphically displayed (Figure 2) for about 10 materials-related experiments to be carried out in a short, 24-hour period with given constraints on five experiment resources (crew IVA time, power consumption, quantity of fluid, etc.). If a solution is not possible, statistics are presented concerning the resource which is the direct cause. Every time a new node is developed during the search, intermediate results are displayed in diagram form.

2) Inference processing: In searching for the solution schedule, depth-priority searching (vertical search) is done using backtracking. Searching and pruning are done in two stages to reduce the computational burden.

3) Computer environment: Using also Knowledge Craft [as published] mainly with LISP on a microVAX-II/GPX and a VAX 8200.

Research for applying artificial intelligence to the aerospace field must continue as a very important research topic. We have discussed an active support expert system for space experiments as an example of applied knowledge processing technology This research has been carried out since FY 1986 as joint research with NASDA.

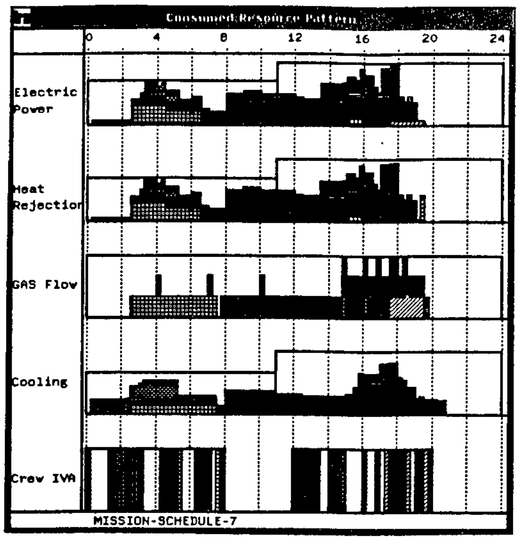

Figure 2. Example of Resource Usage in Scheduling 10 Missions

Vibration Testing of ACT Fuselage

43062055a Tokyo KOGIKEN NYUSU in Japanese Jan 88 pp 10, 11

[Article by ACT research group]

[Text] The ACT whose fuselage model vibration testing was done in order to determine the vibration characteristics of the whole-fuselage model before wind tunnel testing and feed them back in the analysis data. This testing follows the rigidity testing (see KOGIKEN NYUSU No 344) and began in October at the testing grounds at the Chofu airfield laboratory. Since it is the largest-class whole-fuselage elastic model in the country, a special frame for the vibration testing was set up, and in order to obtain the vibration characteristics at any state during flight, sliding parts built into the model of the wind tunnel testing were used, only the front-back and left-right displacement of the model were constrained, and the center of gravity of the model was suspended with a spring coil in such a way as to not affect the vibration characteristics of the whole-fuselage model. For applying vibration, an electrodynamic excitation machine was used, and two vibration application points were selected in order to apply vibration with the vibration mode of the whole-fuselage model separated into symmetrical and anti-symmetrical. The vibration mode was determined using a small semiconductor gauge-type accelerometer which is highly sensitive at low oscillation frequency; 75 points on the entire fuselage were chosen as measurement points, and in taking measurements the positions of the detectors were moved about. For data processing, the excitation force due to random vibration at a point and the acceleration at the measurement points were stored in a data recorder in sequence, the frequency response function was measured with a two-channel Fast-Fourier Transform analyzer, the modal analysis was done with a personal computer, and the modal parameters were determined, including the characteristic frequency,

damping, and the vibration form. Also, the moment of inertia with respect to pitching vibration and the steering actuators built into the model were activated, and measurements were made of the steering elasticity response. Figure 2 shows an example of the results of the vibration testing.

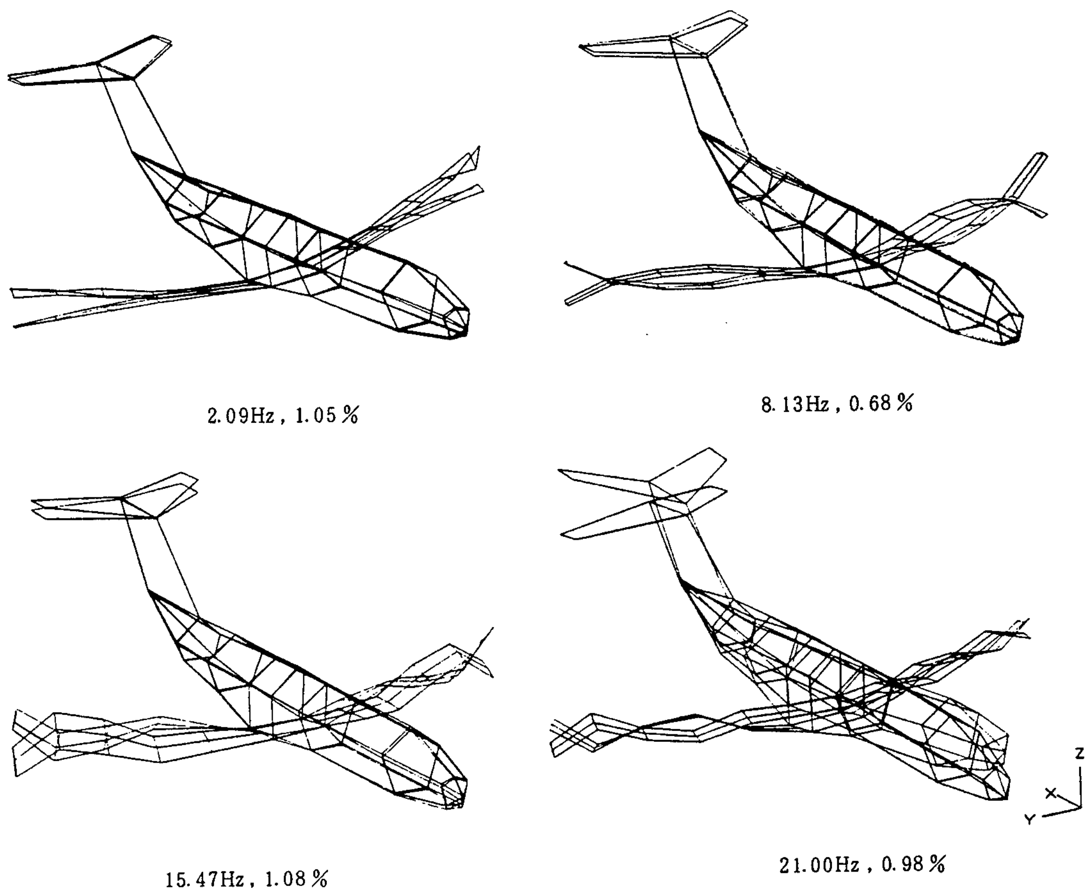

Figure 2. Results of Vibration Testing

13278/9365

New Super Alloys Used in Turbochargers

43066512 Tokyo JIDOSHA GIJUTSU in Japanese Oct 87 pp 1150-1155

[Article by Masashi Yoritaka and Yukio Yamamoto of the Head Office Laboratory, Mazda Technical Institute; Yasuaki Hasegawa, Yokohama Laboratory, Mazda Technical Research Institute; and Tomio Hokari, Development Division, Hitachi Sawa Plant: "Development of Super Heat-Resistant Turbocharger"]

[Text] **1. Introduction**

The turbochargers now used by most automobile manufacturers have turbine blades of inconel 713C (Ni-based Cr-Al-Mo super alloy). Inconel 713C is suitable for mass production because it is relatively cheap and highly castable, and its melting stock can be easily procured. In recent years, however, exhaust gas temperatures have tended to increase because of the compatibility between high automobile output and low fuel consumption, and, particularly, exhaust gas temperature is extremely high. At the same time, creep strength at high temperatures is a problem with turbine blades, which are subjected to great centrifugal forces as they turn at more than 100,000 rpm. The creep strength of inconel 713C is not necessarily sufficient and this has been noted as an engineering bottleneck in the refinement of turbochargers. We have attempted to use a new Ni-based super alloy to replace inconel 713C. Further, the heat resistance of turbine cases is also an important problem. Normally, high-Si ductile cast iron or Ni-resist ductile cast iron is used, but we have sought to use a Co-based super alloy with drastically improved heat resistance.

2. Necessity of Super Heat-Resistant Turbocharger

In general, using a fuel mixing ratio as close to the theoretically ideal air fuel ratio as possible is an effective means of achieving compatibility between turboengine output and fuel consumption. But in the high rotation zone, exhaust gas temperature is so high that the heat resistance reliability of the turbocharger becomes a problem for the engine exhaust system. For this reason, a rich fuel set (rich mixture) has thus far been used reluctantly. Figure 1 is a model showing how, in the high rotation zone, output, fuel consumption and exhaust gas temperature are related to the air fuel ratio. In the past T/C specifications, operation in the hatching zone was the limit. However, to improve output (pe) and fuel

consumption (be) operation in a thinner mixing ratio zone is necessary. Ideally, an intermediate point between pe-Max and be-Min is desirable. To this end, the rise of exhaust gas temperature cannot be avoided and developing a turbocharger with excellent heat resistance has become absolutely necessary.

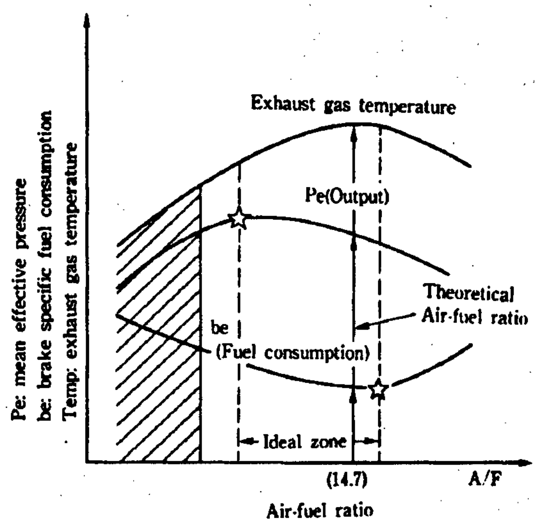

Figure 1. Model for Output, Fuel Consumption, Exhaust Gas Temperature

3. Problems With Conventional Turbochargers

The basic specifications of the turbocharger, the object of this study, are those for the twin-use HT-20 (Hitachi) which has an A/R = 0.9 in (22.86 mm) and a maximum turbine diameter of 66 mm.

Figure 2 is a schematic diagram of the turbocharger plus terminologies used in this paper.

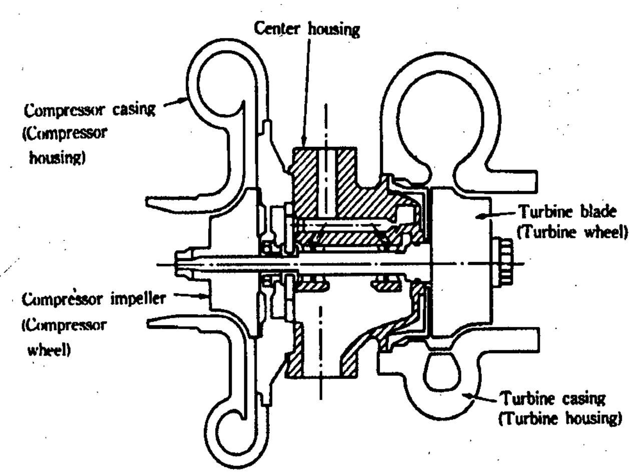

Figure 2. Cross-Section of Turbocharger

In past specifications, inconel 713C was used for the turbine blade and Ni-resist D_2 for the turbine casing. Under these specifications, heat resistance reliability was insufficient and failures soon developed when the turbochargers were used for racing car rotary engines. The failures resulted from damage due to insufficient high-temperature creep strength for the turbine blades and, for turbine casings, thermal deformation, cracking, and oxide film formation due to insufficient high-temperature creep strength and resistance to oxidation.

4. Application of New Materials and Preliminary Test

4.1 Selection of Turbine Blade Materials

Turbine blade materials were selected primarily with a view toward improving high-temperature creep strength. We picked as possible materials the Ni-based alloys TRW-6A, MAR-M247, and TM-321, among the strongest in the world, rather than inconel 713C. Of these, TRW-6A and MAR-M247 are alloys developed in the United States, but TM-321 was developed in Japan. The chemical composition and creep strength of the alloys are shown in Table 1 and Figure 3.

Table 1. Chemical Composition of Turbine Blade Material (Wt%)

	Ni	Cr	Co	Mo	W	Ta	Nb	Al	Ti	C	B	Zr	Other
713C	Bal.	12.5	--	4.2	--	--	2.0	6.1	0.8	0.12	0.012	0.10	
TRW6A	Bal.	6.1	7.5	2.0	5.8	9.0	0.5	5.4	1.0	0.13	0.02	0.13	0.5Re 0.4Hf
MAR. M347	Bal.	8.2	10.0	0.6	10.0	3.0	--	5.5	1.0	0.07	0.02	0.09	1.5Hf
TM321	Bal.	8.1	8.2	--	12.6	4.7	--	5.0	0.8	0.11	0.01	0.05	0.9Hf

TRW-6A has the greatest creep strength, followed by TM-321 and MAR-M247 in that order. All show much greater creep strength than inconel 713C, the conventional material.

4.2 Selection of Turbine Casing Materials

We used the Co-based super alloy FSX414 instead of Ni-resist D_2, as in the past, for turbine casings. Its chemical composition is shown in Table 2 and its high-temperature creep strength in Figure 4. For reference, data for Ni-resist D_5S are also shown.

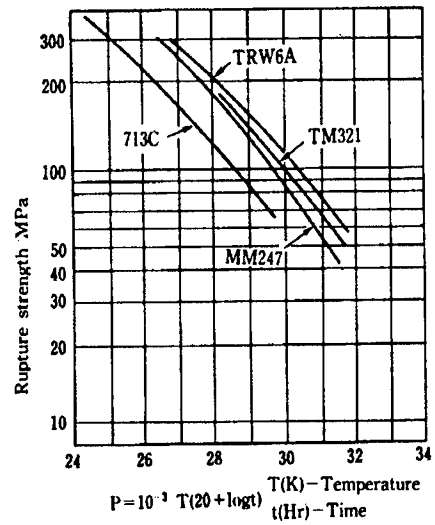

Figure 3. Turbine Blade Material Creep Strength

Table 2. Chemical Composition of Turbine Casing Material

(Wt%)

	Ni	Cr	Co	W	Ta	Al	Ti	C	B	Fe
FSX414	10.0	29.0	Bal.	7.5	--	--	--	0.25	0.01	1.0
	Fe	T.C	Si	Mn	Ni	Cr	P			
Niresist D_2	Bal.	2.5	2.0	1.0	20.0	2.3	0.05			
Niresist D_5S	Bal.	2.0	5.5	0.5	36.0	2.5	0.05			

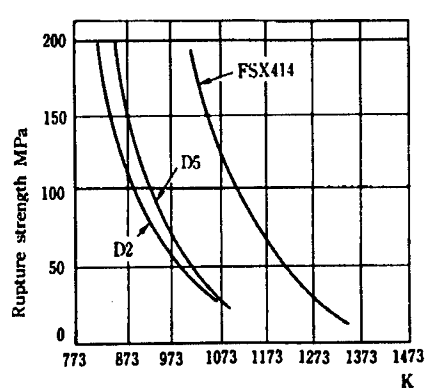

Figure 4. Turbine Casing Material Creep Strength (1,000 Hr)

The reason why we selected the Co-based super alloy FSX414 for turbine casings was largely because of its suitability for atmospheric casting in manufacturing as well as for its excellent creep strength.

4.3 Preliminary Test

To select the best of all eligible materials, it is necessary not only to look for high-temperature creep strength but also resistance to oxidation, castability, and other factors.

Figure 5 shows the results of an oxidation test on various turbine blade alloys.

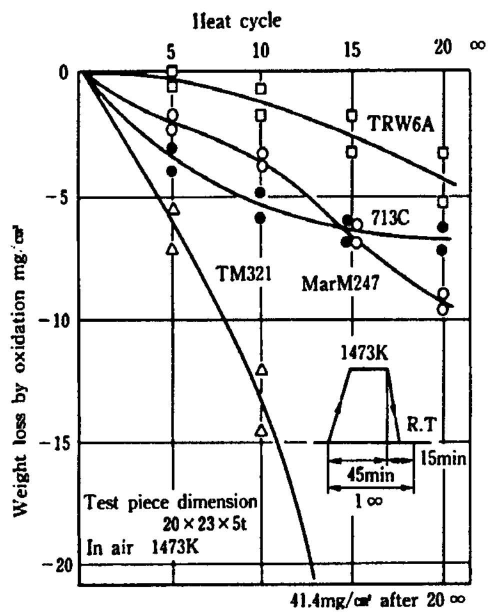

Figure 5. Turbine Blade Material Oxidation Resistance

Compared with inconel 713C, TRW-6A is better while MAR-M247 is generally equal. TM-321 is inferior in oxidation resistance. We have confirmed that alumi-pack cementation can effectively improve resistance to oxidation. We have also carried out an anticorrosion test, but its results are omitted here. As a turbine casing material, FSX414 is much better than Ni-resist D_2 (Figure 6).

The turbine blades were manufactured by lost-wax process vacuum casting, but the turbine casings were manufactured by atmospheric casting. TRW-6A, an eligible alloy for turbine blades, was inferior in castability (with many casting cracks) and we had to give it up. MAR-M247 and TM-321 proved to be practicable.

In using FSX414 for turbine casings, there was no problem with castability.

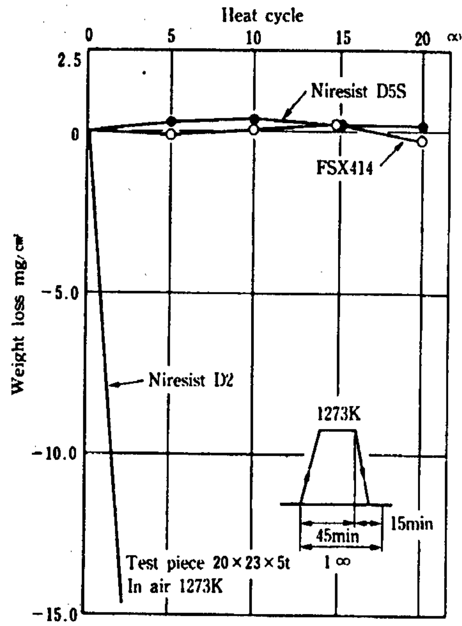

Figure 6. Oxidation-Proof Property

5. Manufacture of Turbocharger Unit Evaluator

We made a unit evaluator (burner rig tester) to evaluate quantitatively the heat resistance reliability of an experimental turbochargers made of new materials.

The evaluator is outlined in Figure 7 and Figure 8 [omitted].

This device uses propane gas as its fuel. It can simulate the exhaust gas conditions of various engines and be freely set within a range of 1,073-1,473 K for combustion gas temperature and of 0.02-0.14 MPa for combustion gas pressure.

6. Evaluation of Super Heat-Resistant Turbocharger

Using our preliminary test and other data, we conducted a burner-rig tester evaluation of our experimental products using MAR-M247 and TM-321 for turbine blades and FSX414 for turbine casings. For comparison, a similar evaluation was made of inconel 713C.

Table 3 shows the manufacturing conditions of the experimental products.

6.1 Rupture Life of Turbine Blades

Figure 9 shows how operating time and combustion gas temperature of the period until the creep rupture of turbine blade tips are related to the number of turbine rotations (representing stress) when they are rearranged using Larson-Miller parameters.

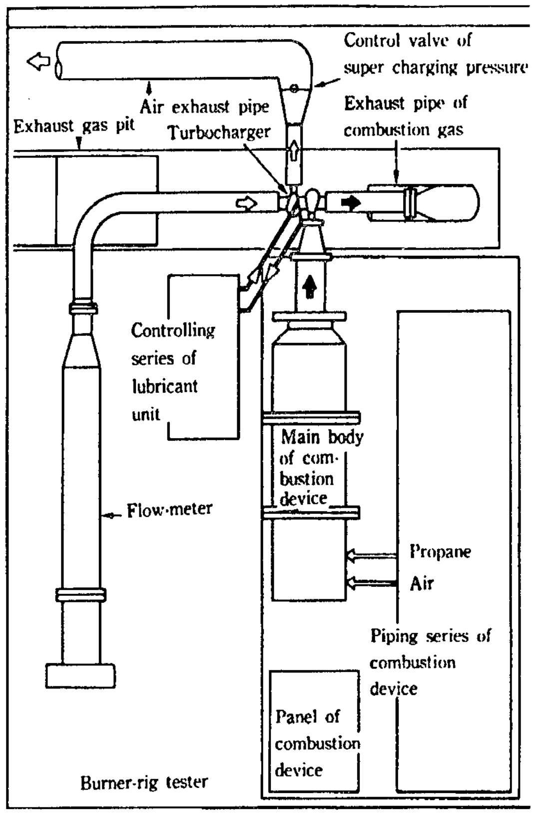

Figure 7. Evaluation System

Table 3. Condition for Trial Production

1. Casting condition for turbine blade (MAR-M247, TM321, INCO 713C)			
Melting temperature			1873 K
Casting temperature			1873 K
Atmosphere			Vacuum
Mold temperature			1323 K Lost-was method
2. Casting and heat treatment conditions of turbine casing (FSX414)			
Melting temperature			1803 K
Casting temperature	1423 K		1803 K
Atmosphere	4 hr	1255 K	Air
Mold temperature		4 hr	1273 K Lost-wax method
Heat treatment			Vacuum heat treatment

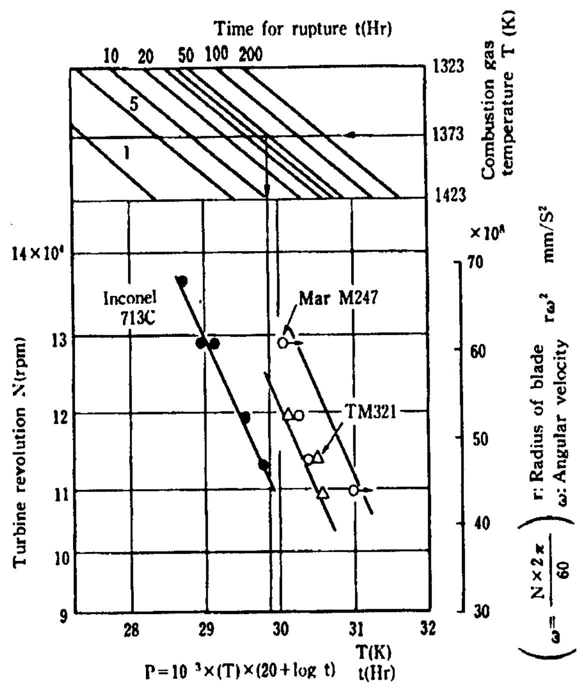

Figure 9. Rupture Life of Turbine Blade

Turbine blades using MAR-M247 and TM-321 have longer rupture lives than turbine blades of inconel 713C and their durability exceeds 1373K50Hr in the practical rotation zone (110,000-130,000 rpm). No significant difference seemed to exist between MAR-M247 and TM-321. The presumed reason why no significant difference appeared in spite of the fact that, as shown in Figure 3, TM-321 was superior in creep strength is that the specific gravity of TM-321 is somewhat greater and when it is used for a rotary body, its specific gravity differential is offset by its excessive centrifugal force.

6.2 Structure Change of Super Alloys

Observation of the turbine blade structure before and after the test revealed that before the test a fine cubic γ' phase was neatly arranged but after the test, the γ' phase became coarse. The high-temperature stability of the γ' phase is particularly important because the high-temperature strength of this phase greatly deteriorates when it is coarse. So, we cut out test pieces from the turbine blades, kept them heated in the atmosphere, observed the progress of the γ' phase change and then compared the results for the different materials. Figure 10 shows how the structure changed as observed through an electron microscope.

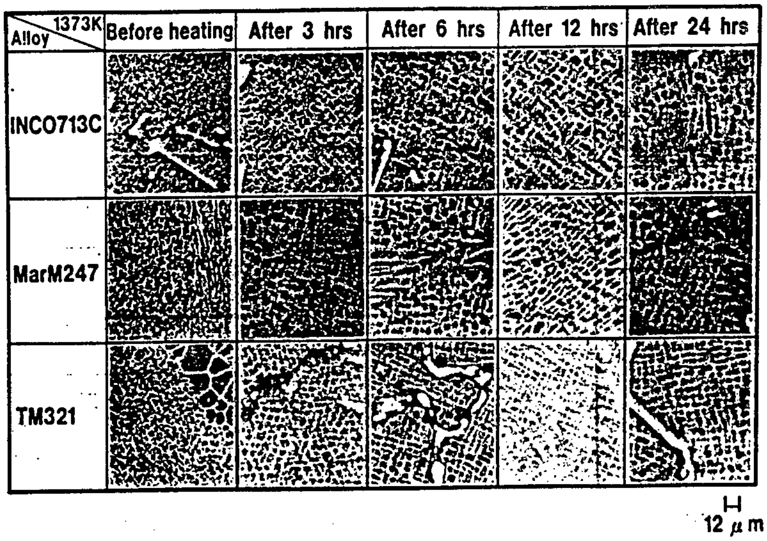

Figure 10. Structure Change of Turbine Blade Material (Microstructure)

Of the three super alloys, the γ' phase became coarse in inconel 713C, which began after 3 hours of heating.

As for MAR-M247 and TM-321, it was to until they had been heated for about 24 hours that the coarsening of the γ' phase could be confirmed in them--and then, only partially.

It can be seen from the above that the γ' phases of MAR-247 and TM-321 are exceedingly stable, as compared with inconel 713C. This result well explains the fact that, as shown in Figure 9, there were great differences in the rupture life of turbine blades.

7. Rupture Mechanism of Turbine Blades

7.1 Rupture Process

To see the process that leads to the rupture of turbine blades, we made tear down checks at intervals of several hours while continuing stationary operation at 11 x 10^4 rpm and 1,423 to 1,443 K. Figure 11 shows the measurement results of the elongation of MAR-M247 and TM-321 turbine blades in the radial direction.

We learned that turbine blades of both types suddenly became elongated at the initial stage, then entered a period of stability, and at this stage, suddenly became elongated again. This closely resembles the general pattern of creep deformation. An elongation range of 0.4 to 0.8 mm was observed in our measurement, but, at both stages, the degree of elongation differs considerably between turbine blades. It is believed that this is not a mere dispersion but is due to the difference of casting structure, as will be demonstrated later.

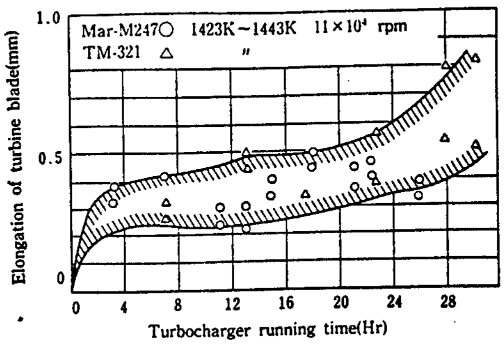

Figure 11. Elongation in Tip of Blade

Figure 12 [omitted] shows the results of the more detailed observation of the progression from the final stage to the burst.

Figure 13 is a modeled explanation of the rupture process as a whole.

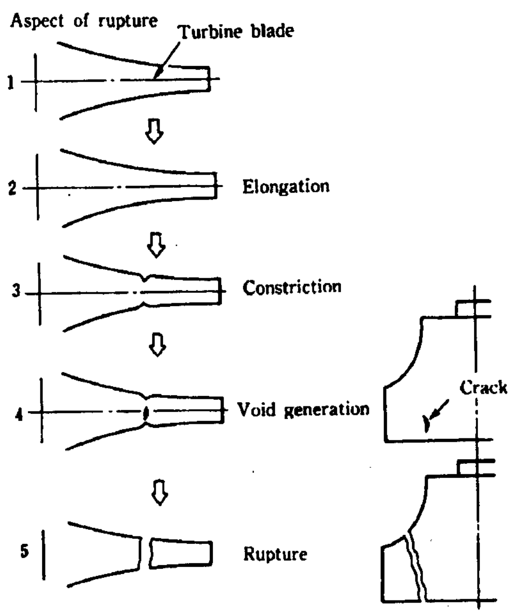

Figure 13. Rupture Mechanism of Turbine Blade

First, the turbine blade becomes somewhat elongated. This elongation gradually increases and construction develops about 10 mm from the tip. Further, a void due to creep deformation forms in the constricted portion. This void grows larger with the progress of the deformation until it finally reaches the surface as a crack. Eventually, the blade bursts due to contact between the turbine blade and the turbine casing. As indicated in Figure 14, stress is high and severe temperature conditions exist at the point of constriction.

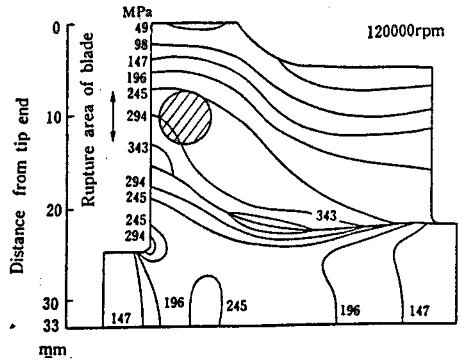

Figure 14. Stress Distribution of Turbine Blade

7.2 Effects of Coagulated Structure

Creep is the main cause of turbine blade rupture, but, as seen in Figure 11, tip elongation differs considerably among blades of the same turbine. This is because structure differs from blade to blade. Figure 15 [omitted] shows photographs of the structure of two symmetrical blades.

There are creep-induced constrictions in the center of both structure photographs. Though no cracks are yet visible in the upper photograph, in the lower photograph there are already many cracks and, moreover, they are on the grain boundary in the central part of the blade. This fact indicates that the grain boundary profoundly affects the rupture life of blades.

8. Discussion

These blades were manufactured using ordinary casting methods that did not involve any special structure control. Yet, many blades displayed a unidirectionally coagulated structure. Figure 16 [omitted] is a typical example of a unidirectionally coagulated structure. The apparent explanation of why such a coagulated structure was obtained is that both MAR-M247 and TM-321 are alloy components liable to be coagulated unidirectionally and that the shape of the turbine blades gradually changes from the thin tip section to the thick central part.

But to obtain uniform unidirectionally coagulated structure for all blades, some form of positive structure control must be used.

9. Conclusion

We ultimately adopted the Ni-based super alloy MAR-M247 for turbine blades and the Co-based super alloy FSX414 for turbine casings, taking the procurability of the necessary melting stock into consideration. In the process, we gained a better understanding of the basic material characteristics of the various heat-resistant materials, completed a burner rig tester capable of heat resistance evaluation and confirmed that the operational temperature of the turbocharger had greatly improved. Moreover, we reached the following conclusions:

1. The rupture life of turbine blades is closely related to the high-temperature stability of the γ' phase of super alloys.

2. The rupture mechanism begins with the elongation of the turbine blade, progresses to the formation of a creep void in the interior, develops into a crack on the surface and finally ends in rupture.

3. Even with the same material, casting structure differs from blade to blade but destruction starts from the grain boundary in the interior. It can be said that blade strength increases as it approaches a unidirectional coagulated structure without a lateral-direction grain boundary.

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[Article by Tokahiro Suzuki, Electronics Policy Section, Machinery Information Industries Bureau, Ministry of International Trade and Industry: "Points of Fiscal 1988 Informationalization-Related Measures, Programs for Realization of Highly Information-Oriented Society"]

[Text] Preface

The informationalization in Japan is advancing smoothly, with the number of general purpose computers installed exceeding 200,000. In addition, the information-related industry has now grown to become the leading industry of the Japanese economy, occupying 6.4 percent of the total national growth and reaching a scale of Y17 trillion.

Naturally, the development of informationalization not only promotes the rationalization of industry activities, attainment of a high-level industrial structure, and integration of creative knowledge, but also greatly contributes to the realization of a stable domestic life and mutual understanding internationally.

In order for Japan's economy to attain stable growth on a medium- or long-term basis, not only the development of the information industry, which is the leading industry, but also progress in wide informationalization, ranging from industries to homes, is necessary. So far, both the information industry and informationalization have been focused on quantitative expansion during one period, leaving many basic and qualitative problems to be solved, and exact responses to these subjects have become necessary for the smooth realization of a highly information-oriented society. That is, importance needs to be placed on improvement of the informationalization bases, such as nurturing capable men who support an information-oriented society, enrichment of information-oriented education, measures to correct quantitative and qualitative shortages of software, and improvement of data bases which lag behind those of foreign countries.

The Ministry of International Trade and Industry [MITI] will continue to develop overall informationalization measures again in fiscal 1988 while taking the above viewpoint into consideration.

The informationalization-related measures for fiscal 1988 are outlined below.

1. Promotion of Informationalization Education and Capable Personnel Training Measures

The pressing task of responding to the information processing necessity in the industrial and societal fields, which have become diversified and high-level along with the development of informationalization, requires the training of capable people who support informationalization in the industrial and societal fields and the promotion of computer utilization in school education.

In fiscal 1988, overall measures for informationalization education and the training of capable people will be promoted, with importance placed on promoting the concept of an information academy.

(1) Promoting information academy concept

To overcome the shortage of software engineers, information-related educational facilities, such as colleges, are also expanding rapidly. As a result, the problem involving experts' quality has come to the fore. Therefore, the idea of an information academy will be promoted in order to train superior information processing engineers and activate local information industries.

(a) Promoting idea of information academy

A central information education laboratory (central information academy) will conduct investigations and research involving the education of software engineers and train instructors for information processing education institutions. A local information academy will be established in each district to spread the education method based on the needs of the industry, and to enrich the information processing education in the district.

[Budget] Promotion of information academy concept: Y80 million (Y70 million)

Note: The amount enclosed in parentheses is the budget in fiscal 1987. The same format will be followed throughout this article.

(b) Development of coursework for information processing engineers (CAROL system)

Since information processing engineers (system engineers and high-grade programmers) are quite insufficient, both quantitatively and qualitatively, software will be developed for information processing engineer training, based on the needs of the industry as part of the information academy concept, and will be spread.

More specifically, 1 establishment of specifications for a CAI system (CAROL system) for educating information processing engineers, 2 definition of the standard curriculum for educating information processing engineers, and 3 spread of the CAROL system, will be attempted.

[Financial investment and loan] Development of coursework for information processing engineers

Industrial investment and loan: Y900 million (Y600 million)

(2) Promoting computer utilization in school education

Today, with the rapid advances in informationalization, individual segments of the population need to be made less hesitant to use such information devices as computers (promotion of computer literacy). Therefore, computers should be included in school education so that people will accept computers as familiar tools, beginning in childhood. Also, education including computer use is anticipated to effectively diversify education methods.

From this viewpoint, various attempts are being made to promote computer utilization in school education, with the Information Processing Promotion Association (IPA) and Computer Education Development Center as the nuclei.

(a) Investigation of basic techniques for educational informational processing

To promote computer utilization in school education, research and development and basic investigations will be conducted on user-friendly computers for school education.

[Budget] Investigation of basic techniques for educational information processing: Y240 million (Y220 million)

2. Promotion of Overall Software Measures

A stable supply of good-quality software is indispensable for realizing a highly information-oriented society. At present, however, the rapid development of informationalization and rapid spread of computers have

brought an explosive increase in the demand for software, with the annual increase rate having reached about 26 percent. On the other hand, there has been a chronic shortage of information processing engineers and their supply is still limited. Therefore, their annual increase rate is only 13 percent. As a result, the gap between demand and supply may increase in the future, resulting in a software crisis. In addition, the software portion of information processing expenses is steadily increasing, while the demands for software quality, such as reliability, have become extremely strict.

For this reason, the Sigma plan, etc. will be promoted positively by the (IPA), a central institution designated to promote software measures.

(1) IPA's attempts

The attempt to build the software production industrialization system (sigma system), was started in fiscal 1985 with the goal of sharply enhancing productivity and reliability of software development. The following efforts will also be made:

(a) Sigma system building attempt

[Financial investment and loan] Industrial investment: Y3 billion (Y2.9 billion); Japan development bank loan: Y500 million (Y300 million)

(b) General purpose program development and circulation promotion attempt

[Financial investment and loan] Industrial investment: Y1.8 billion (Y1.5 billion)

(c) IPA's general accounting

[Budget] Y1.21 billion (Y1.35 billion)

Incidentally, from the viewpoints of realizing a highly information-oriented society and expanding internal demands, the penetration of informationalization will be requested at the personal and domestic levels from now on. Through improving the common interface for the personally- and domestically-oriented information-related devices, the base of the above-mentioned information penetration, and the basic software for using the common interface, the use of devices with the common interface will be promoted.

(d) Attempt to improve common development environment for basic devices of highly information-oriented society

[Financial investment and loan] Industrial investment: Y300 million (new)

(2) Loan for information processing enhancement (Japan Development Bank's loan)

Equipment funds (partly nonequipment funds) are loaned for the automation of software development, training of software development engineers, and software development for interenterprise systems. (Most preferential interest)

Incidentally, in consideration of the importance of promoting the training of capable personnel to bear the highly information-oriented society in the future, the buildings, equipment, and non-equipment items for information processing engineering training programs performed by such entities as colleges are being added to loan targets.

[Financial investment and loan] Y5 billion (part of Y86.5 billion)

3. Promotion of Information Personalization

To realize a highly information-oriented society responding to advancements in the distributed processing of information and the expansion of the user layer of information-related devices, a man-machine interface is needed that would allow general users in a wide area to perform high-level information processing without experiencing incompatibility.

However, the current computers make full utilization difficult unless the user is a specialist, and it is also difficult to apply them to a nonroutine business. Therefore, the developments of 1 a processing technique for analog information, such as images, 2 a Japanese and ambiguous information processing technique, and 3 a human-engineering interface, is occurring while the users' needs are being taken into consideration.

[Budget] Development of basic techniques for future distributed information processing environment: Y120 million (new).

4. Improvement of Data Base and Enrichment of Information Supply Service

The data base, together with hardware, software, and capable personnel, is one of the pillars supporting an information-oriented society, and improvement of the data base is a precondition of informationalization. However, domestic data base improvement is far behind that of foreign countries and has been designated an urgent task.

To promote data base improvement in Japan, such measures as promotion of data base building in the private sector, promotion of public data base building, training of distributors, expansion of the supply of

government-owned data to the private sector, and improvements in the data base utilization environment will be performed.

(1) Promotion of important data base building

An investigation of a development plan directed toward building data bases will be carried out on those data bases important for Japan's economic society, through the cooperation of industry and university officials in advanced technology (fine ceramics, new materials, etc.), energy, and security fields.

[Budget] Promotion of important data base building: Y60 million (Y66 million)

(2) Promoting training international data base distributors

An investigation will be made of the social and technical requirements, resources, and form necessary for data base distributors and producers to build an international distributor system and of the software needed to facilitate and enable data base retrieval.

[Budget] Promotion of training international data base distributors: Y7 million (Y8 million)

(3) Investigation involving data base and information supply service

An investigation will be made of concrete measures to improve and promote data base, agent retrieval, and image and voice information supply services, while taking into consideration the supply and utilization requirements.

[Budget] Investigation involving data base and information supply service: Y7 million (Y8 million)

(4) Building public data bases and expanding the supply of government-owned data bases to the public sector

The public data bases (technology-, patent-, and medium and small enterprise-related data bases) necessary for promoting MITI's administration will be built as before. However, these data bases will be supplied to the private sector on a larger scale, and government-owned data, such as certain statistics, will be made available to the private sector in the form of magnetic tape to facilitate use and improve supply conditions.

(5) Supporting data base building in private sector

The Japan Development Bank will invest money in an entity to build a basic data base necessary for the future development of industrial and

social activities, and will finance equipment and nonequipment funds for data base building.

(a) Financing data base building expenses (Japan Development Bank's loan)

Financing of the equipment acquired by an entity performing information supply service when building a data base and the nonequipment items related to the data base building expenses (special interest 4)

[Financial investment and loan] Part of promotion of information processing and communication systematization: Y14.4 billion (included in Y86.5 billion)

(b) Financing of basic data base building entity (Japan Development Bank's loan)

Financing of an entity to perform information supply services to build a "basic data base," necessary for developing industrial and social activities and local communities (Japan Development Bank's financing)

[Financial investment and loan] Part of promotion of information processing and communication systematization: Y14.4 billion (included in Y86.5 billion)

(6) Improvement of data base ledger

The ledger which collects the data base ledgers (kinds, locations, contents, etc.), aimed at various currently usable data bases in Japan, will be improved as before.

(7) Data base engineer examination system

A data base engineer examination will be established as one measure to train and secure data base engineers for effective use of data bases.

5. Promotion of Security of Mutual Operability and Standardization of Systems

With the trend toward networking in society, various information-related devices, as well as disconnected and mutually unrelated systems, have posed problems.

Even for computer users, the necessity for connecting different types of computers is on the rise.

To resolve this problem, OSI-related standardization work is progressing, but from now on, computer manufacturers and users must grapple positively with this problem.

(1) Promotion of OSI through international contact

1 Holding Japanese and EC high-level meetings and specialists' meetings involving OSI promotion,

2 Promotion of mutual contact among POSI (Japan), SPAG (EC), and COS (United States).

(2) Promotion of standardization of advanced and elastic information-related technology

Establishment of OSI standards will be promoted based on the Japan Industrial Standard (JIS) while the ISO's (International Standardization Organization) examination results are being studied.

(3) Research and development of data base systems for mutual operation of computers

Since the present mutually disconnected data bases have been built mosaically, users who need certain information must use the terminal connected to each data base. The data is also inconvenient in that it is usable only by characters and limited graphics. To respond to future activities in various fields of society, the realization of a single system which solves these problems, becoming the base of a highly information-oriented society, is indispensable.

Therefore, the following OSI-related activities are being performed:

1 The generation of OSI-based subsets and preparation of functional standards,

2 Verification and evaluation using a model system,

3 Testing for and verification of mutual connection based on OSI.

In addition, research and development are being performed on distributed data base system techniques, multimedia techniques, and other highly reliable techniques.

[Budget] Research and development of data base systems for mutual operation of computers: Y1.15 billion (Y1.05 billion)

(4) Grappling with implementation of mutual connection test based on OSI

The Information Processing Mutual Operation Technology Association (INTAP) is planning and preparing for implementing a mutual connection test.

6. Promotion of Industrial Informationalization

The informationalization of industry has lead the informationalization movement in Japan as necessary for the informationalization of the economic society. From now on, however informationalization needs to be advanced across the boundaries of enterprise and industry through the building of an interenterprise network.

Therefore, such measures as the taxation system and financial investment and loan will be adapted to promote the building of interenterprise networks, while the informationalization of individual industries, such as electric power, will be promoted as before, fully utilizing a linkage guide.

Also, to improve the development base of the information industry which supports informationalization, financial investments and loans will be secured for computer promotion.

In addition, the target of Japan Development Bank's financing and loan policies will be expanded to include those shown below:

1. Promoting "integration and improvement of office devices" from the viewpoint of OA expansion in industry.

2. Those who perform "system integration services," which supply users with optimum systems by systematically combining hardware, software, and expertise involving telecommunications and computers and by packaging processes ranging from consultation and system design to selection and installation of hardware, system development, staff education, and maintenance, in response to networking.

3. As society increases its dependency on computers and information systems, there is the increased fear that everything from social economic activities to individual information may be significantly affected by the current level of reliability and secrecy. Therefore, the "improvement and promotion of informationalization safety measures" have been added to the Japan Development Bank's financing and loan policy target fields.

4. The "highvision development and promotion center" has been added to improve the extent of utilization of high-quality television (highvision), providing such functions as high minuteness, expanded visual field, and increased quantity of information displayed.

(1) Establishment of taxation system to promote the building of a networked society (taxation system)

A new taxation system will be established permitting the selection of a 7 percent deduction of the expense (rent) incurred in acquiring the

computer and peripheral equipment to configure an interenterprise network, or of a special 30 percent repayment during the first year.

This taxation system is being promoted from the viewpoint that interenterprise networks will become the base for spreading informationalization to society and homes in the future, and that contributing to the expansion of domestic demands, an important aspect of Japan's economy, in an attempt to realize a highly information-oriented society, will bring a higher-lever industrial structure and make leisure more enjoyable for the citizens.

(2) Establishment of reserve fund for integrated system maintenance

For the sound development of an integrated system service (system integration service), a taxation system will be established to allow accumulation of reserve funds to be used for expenses necessary for maintaining a system when the person who is operating a specific information service builds and supplies the specific system.

(3) Establishment of taxation deduction and special repayment systems for high stabilization support equipment of computer system

A new taxation system will be established to allow a 7 percent tax deduction or a special 30 percent repayment during the first year for the acquisition price (including rent) of the specific building (backup center) and equipment acquired by a person who is operating a computer system and which become bases of system safety measures.

(4) Computer promotion loan (Japan Development Bank's loan)

Funds are loaned toward the rental of computers from the Japan Electronic Computer Corp. (JECC). (Most preferential special interest)

[Financial investment and loan] Y71 billion (included in Y86.5 billion)

(5) Information processing and communications systematization promotion loan (Japan Development Bank's financing and loan)

Financing and loans will be made for the equipment utilized in systems which become the bases of promoting industrial informationalization, such as:

1 Information processing systems among multiple enterprises, 2 Information processing systems for information processing service businesses and information supply service businesses, 3 mainly social systems, such as those involving medical treatment, traffic, and disaster prevention, 4 so-called VAN and information processing CATV, 5 Videotex system, 6 locally promoted information processing and communications systems, 7 office device integration and improvement

promotion, 8 system integrator training, and 9 highvision development, spread, and promotion centers.

Incidentally, measures involving data bases, district informationalization, and future informationalization-based cities will be shown separately.

[Financial investment and loan] Y14.4 billion (included in Y86.5 billion)

(6) Information processing improvement loan (mentioned earlier)

(7) Improvement in reliability of information devices (Japan Development Bank's loan)

In a highly information-oriented society, reliability and performance have to be sharply improved for information-related devices, parts, and materials. In manufacturing information devices, etc., loans will be allowed for investing in reliability improvement.

[Financial investment and loan] Y13 billion (included in Y86.5 billion)

(8) Government-guaranteed loans related to low-interest loans involving IPA

Government guarantees will be given for loans from low-interest loan funds used for system design and program development related to the IPA's information systems that will be used in common in an industry or between two different industries.

(9) Improvement and promotion of informationalization safety measures (Japan Development Bank's and Hokuto Financial Corp.'s financing and loans)

To promote the smooth building of a highly information-oriented society, the reliability and security of computer systems must be guaranteed. At the same time, once a system is down, it has to be replaced or reorganized as soon as possible. Therefore, Japan Development Bank and Hokuto Finance Corp. will offer new financing and loans for "promoting high security for computer systems" and "backup center improvement promotion."

[Financial investment and loan] Y4.7 billion (new)

(10) Promotion of informationalization of individual industries

As for individual industries, such as electric power, which are highly important in district informationalization and affect other industries, informationalization needs for each industry will be investigated and a

"linkage guide" will be provided based on the "law related to promotion of information processing."

7. Promotion of Information-Related Technology Development

From now on, the incessant promotion of technology development is indispensable to Japan's economic system for realizing an energetic, highly information-oriented society and for dealing with the diverse necessities of industry and society.

Therefore, positive promotion will also be made in fiscal 1988 of the research and development of the fifth-generation computer, development of new functional elements such as bioelements, research and development of computer-mutual-operation data base systems, scientific and technological high-speed computation systems, and advanced social systems.

Moreover, the financing and loan functions of the basic technology research promotion center will be fully utilized and, at the same time, a taxation system will be prepared so that financing loss reserve funds can be accumulated by the industries contributing to the center's financing project.

(1) Research and development of fifth-generation computer

Aimed at the beginning of the 1990s, the research and development of the new-generation computer (fifth-generation computer) will be powerfully promoted as previously by freely using innovative technologies, such as artificial intelligence and high-level parallel processing.

In fiscal 1988, a partial system design will be performed to represent inference subsystems and knowledge data base subsystems.

[Budget] Y5.75 billion (Y5.63 billion)

(2) Research and development of scientific and technological high-speed computation system (large-scale project)

Research and development will be conducted on a high-speed computation system (supercomputer) with a sharply increased operation speed for use in scientific and technological computations, such as the processing of images sent from a weather satellite.

[Budget] Y2.83 billion (Y2.95 billion)

(3) Research and development of computer-mutual-operation (interoperable) data base systems (large-scale project) (mentioned earlier)

[Budget] Y1.15 billion (Y1.05 billion)

(4) Superconductive materials and elements

Research and development will be started for investigating the mechanism of high-temperature superconductive materials, searching for normal-temperature superconductive materials, developing innovative processing technologies, and finding new functional elements using high-temperature superconductive materials.

[Budget] Y1.08 billion (new)

(5) Research and development of diagnostic support systems

To enhance the medical treatment level and aid medical treatment by informationalizing medical treatment, a consultation system aimed at the direct support of doctors' diagnostic duties will be developed as before.

[Budget] Y410 million (Y170 million)

(6) Utilization of basic technology research promotion center

The basic technology research promotion center is a general service institute which supports technological development in the private sector and supplies the risk money required for research and development of basic technologies and cooperative projects by linking industry and university officials. This center finances cooperative R&D companies, provides conditional interest-free loans, and mediates in cooperative research between a company and a national laboratory. In 1988, technological development will continue to be promoted by exploiting this center.

Also, to encourage positive participation of private enterprises in projects funded by this center, new taxation measures will be adopted.

[Financial investment and loan] Industrial financing and loans: Y29.5 billion (Y25 billion)

Establishment of basic technology research investment loss reserve fund system (taxation system)

A system, financed by the basic technology research promotion center, will be established to allow inclusion of 10 percent of the investment amount in pecuniary loss for an entrepreneur who finances an R&D project.

8. Promotion of District Informationalization

To smoothly realize a high-level information-oriented society, balanced informationalization has to be promoted throughout the country while informationalization differences are being corrected among districts.

For this reason, the new media community concept will be promoted to develop and spread various information systems that respond to the needs of local communities. At the same time, a district informationalization base facility (new media center) will be improved and promoted.

(1) Promotion of new media community concept

A district which intends to install a model information system in an applied and developed form will be specified as a new media community concept application development district and a new financing system will be established by the Japan Development Bank for application development districts.

After a model information system built in a model district has been assigned standard specifications, it is stored in a data base and is used to promote district informationalization by sharing the data base with the districts having the same needs.

[Budget] Y50 million (Y50 million)

[Financial investment and loan] Y12.7 billion (included in Y86.5 billion)

(2) Improvement and promotion of district informationalization base facility (new media center) based on private sector activation law

For improving and promoting the informationalization base facility (new media center), which is expected to be the focal points of informationalization in local districts and to be useful for developing district industry and economy, a taxation measure will be adopted, in addition to conventional assistance, to allow the entrepreneurs financing the improvement business corporation of this facility to enjoy the income deduction system for the amount corresponding to 10 percent of their financing amounts.

(a) Financing and loans for new media center building corporation (financing and loans from Japan Development Bank and Hokuto Finance Corp.)

[Financial investment and loan] Included in Y13 billion (new)

(b) Expansion of taxation measures related to new media center

1 Income deduction of 10 percent of the amount invested for an entrepreneur who will finance the new media center improvement corporation

2 Easing of applicable requirements

(3) Others

(a) District informationalization base improvement loan (Hokuto Finance Corp.'s financing and loans)

[Financial investment and loan] Y2 billion (included in Y135 billion)

(b) District informationalization promotion financing and loans (Hokuto Finance Corp.'s financing and loans)

[Financial investment and loan] Y2.8 billion (included in Y135 billion)

(c) District information processing and communications systematization financing and loans (Japan Development Bank's financing and loans)

[Financial investment and loans] Y1.6 billion (included in Y110 billion)

(d) Financing the new media community concept promotion corporation of the base technology research promotion center

[Financial investment and loan] Included in Y29.5 billion (included in Y25 billion)

(4) Social capital improvement accounts (NTT interest-free loan)

The interest-free loan system, based on the social capital improvement accounts which were approved in the fiscal 1987 supplementary budget, will be expanded and continued as shown below.

1. Efforts involving new media community concept districts,

2. Overall city management base improvement efforts,

3. Back-up center,

4. Transfer-correspondence general information processing system,

5. Highvision development and dissemination promotion center.

9. Cooperation with Developing Countries in Informationalization

For international development of informationalization, cooperation will occur with developing countries, including the Pacific region.

(1) Research and cooperation involving machine translation systems among neighboring countries

To promote the interchange of technologies and culture among Japan's neighboring countries and further development of these countries, research cooperation will be started to develop machine translation

systems for use among the Japanese, Chinese, Thai, Malay, and Indonesian languages, to remove the language barriers between Japanese and these languages.

[Budget] From the budget for the research cooperation promotion and support attempts and research cooperation attempts: Y340 million (Y150 million)

(2) Promotion of international informationalization cooperation center's efforts

To support the development of foreign countries' economy and industry by promoting the informationalization of developing countries, seminars to train engineers who are to become the nuclei of informationalization promotion will be held, and Japanese engineers will be sent to developing countries to guide the informationalization process.

[Budget] From the technological cooperation attempt expense aid: Y240 million (Y240 million)

(3) Investigation of software development and circulation base improvement in ASEAN countries

For nurturing the software industry, which has been attracting attention as an export-oriented industry that does not require large-scale equipment investments, and for promotion of an international vertical division of labor, improvement of the software development and circulation base appropriate for the present state of each ASEAN country's software industry is investigated for future technological cooperation.

[Budget] Included in Y30 million (new)

10. Construction of Future Information-Oriented Cities

From the viewpoints of promoting the realization of a highly information-oriented society and presenting domestic demands, acceleration of investments in informationalization is indispensable for these individual fields: society, industry, and homes. Therefore, promotion of the spread of information systems throughout society will be triggered by designating the fields for the building of advanced information systems expected to be introduced in specific model cities around the 21st century, and by presenting construction of the ideal network systems for general promotion of informationalization of each field.

Overall Outline

1 Building of a future city in which a highly functional business section, operating 24 hours, is fused with pleasant living conditions and the workplace is located near the residences.

2 Improvement of the information infrastructure backing up the supply of high-level information services, such as building local LANs with optical fiber, etc., construction of a central information center to perform local management and creation of widespread VAN networks.

3 Introduction of advanced information application systems, improvement of social functions, nurturing the information industry (new media business), and determining demands related to informationalization, such as improving existing industries.

4 Construction of world business zones and hotels to support overseas enterprises' inroads into Japan and improvement of heliports to secure access from airports, as measures for internationalization.

5 Investigation of the introduction of high-tech model systems not included in the information field, such as new energy supply systems, high-speed material flow systems, etc.

[Budget] New society-development-type machine information system introduction promotion system: Y0.1 billion (Y30 million)

[Financial investment and loan] Information processing and communications systematization promotion financing and loans (Japan Development Bank) included in Y14.4 billion (new)

Local information processing and communications systematization promotion financing and loans (Japan Development Bank) included in Y1 billion (new)

District informationalization promotion financing and loans (Hokuto Finance Corp.) included in Y3.1 billion (new)

[Social capital improvement accounts] Japan Development Bank and Hokuto Finance Corp. (new)

[Taxation system]

(National tax)

The following measures will be adopted to promote large-scale local development (information-oriented future city concept) to deal with the informationalization and internationalization of economic society.

① A system will be established to allow special repayment of 20 percent of acquisition prices (10 percent for buildings) for the specific facilities acquired by third sectors (general district management efforts) who maintain and manage the district's high-level city functions, such as safety management and information supply, for the entire development district in accordance with the above concept.

② Inclusion of the amount corresponding to 10 percent of an investment will be allowed for an entrepreneur who finances a third sector which makes a general district management effort.

(Local tax)

A third sector performing a general district management effort can

① adopt a reduction measure for the specific real estate acquired in a development district (real estate acquisition tax);

② reduce the taxation standard to half for fixed property acquired, for 5 years following acquisition (fixed property tax);

③ adopt a tax-free measure for a piece of land which has been acquired in a development district (special land holdings tax);

④ adopt a tax-free measure and a special measure for the taxation standard involving the facilities used in the effort (establishment tax).

20,111/09599

Development of Materials for New Bathyvessel Described

43067533 Tokyo KAIYO KAGAKU in Japanese Nov 87 pp 632-640

[Article by Endo Michimasa, professor, Tokai University, director of Marine Science and Technology Center; first paragraph is editorial introduction]

[Text] Bathyvessels, which are steadily producing results in deep seabed investigations, are complex and precise systems incorporating technology from a number of engineering fields. This article will focus on the critically important materials used in the pressure-resistant shell together with buoyant materials, assessing the main points of their development and the status of their practical application.

1. Development Status and Necessary Functions

Bathyvessels are the most effective means for the direct investigation of seabed configurations, crustal structures, and mineral and biological resources. In the United States and France, bathyvessels of the 2,000-3,000 m class have been operating for more than 10 years, and recently bathyvessels of the 6,000 m class have been constructed. In Japan, "Shinkai 2,000" has made detailed surveys of the waters around Japan, making it possible to obtain new information and to open the door to understanding deep seabed substances from various scientific angles. Consequently, it is expected that joint surveys will be carried out by Japan and the United States, and Japan and France, respectively. In order to expand the scope of deep ocean surveys, the development and construction of a 6,500-m class bathyvessel, the deepest ever in the world, is underway with completion scheduled for autumn 1989.

Despite its small size, the bathyvessel is a complex and intricate system incorporating technology from a number of engineering fields. Its most important functional requirements are hydraulic pressure resistance, compactness, light weight, and silence. It is, therefore, necessary to develop a light yet extremely strong pressure-resistant shell, oil-immersed pressure equalizing equipment and buoyant materials with high strength and low specific gravity, and to minimize the level of noise radiated in the water. The development of various materials to meet these requirements and the processing technologies for these materials is a fundamental task.

2. Development and Practicalization of Materials for Pressure-Resistant Shell

(1) Necessary Properties for Materials for Pressure-Resistant Shell

The ability of a pressure-resistant shell to withstand intense hydraulic pressure depends on its shape and dimensions as well as the materials used. Compared with the materials used for rockets in terms of their essential properties, the strength required of the former is on the same level as that for the latter, but the bathysphere requires a very thick plate. Further, the materials used in bathyspheres must have greater destructive toughness and greater SCC and fatigue resistance, the former because of the extreme conditions and environment in which they operate. Additionally, precision engineering technologies--such as molding, welding, and machining of thick plates--and quality control are needed.

(2) Diving Depth and Strength of Materials for Pressure Resistant Shell

In the selection and development of these materials, the properties described above should be evaluated. The relationship of proof stress and specific strength with diving depth and weight, and the effects on reliability, life, processability and the expense of construction and maintenance should also be examined. Furthermore, the balance between these properties should be taken into consideration. Materials that have been considered include heat-treated low alloy steel, heat-treated high alloy steel, and titanium alloy, but as diving depth increases larger proof stress and greater specific strength are required. While abroad the HY series of the U.S. Navy (0.2% proof stress 56, 70 kgf/mm^2 class) is in practical use for bathyspheres up to the 2,000 m class, high toughness high strength NS 90 steel (0.2% proof stress 90 kgf/mm^2) developed in Japan has been put to practical use for the first time in the "Shinkai 2000." Since a deeper-diving bathyvessel requires materials with greater strength, 10 Ni 8 Co steel (0.2% proof stress 120 kgf/mm^2) has been developed. This material appears to have good prospects for practical use. However, in order to make the vessel smaller and lighter and to improve its resistance to sea water, titanium alloy Ti-6 Al-4 VELI (0.2% proof stress 81 kgf/mm^2) with a high specific strength has been developed. A pressure-resistant spherical shell for a 6,500 m bathyvessel is being made from this material.

(3) NS 90 Steel and 10 Ni 8 Co Steel

Both of these steels are quenched and tempered for high toughness and tensile strength. Both feature a low carbon-tempered martensite structure produced by heat treatments--double quenching and tempering (the former is 5% Ni-Mo-Cr steel and the latter 10 Ni-8 Co-2 Cr-1 Mo steel). The main points regarding material development are to ensure high strength as well as toughness, to secure ductility and SCC and fatigue properties, and to ensure that it is easy to weld and to process. The engineering method used to manufacture a pressure-resistant shell depends on the quality of the material together with the design requirements for processing precision (the degree of sphericity and the precision of the thickness of a plate). In particular, as diving depth increases greater processing precision is

demanded to hold weight increases in check and the level of sophistication demanded of the engineering and controlling technologies advances from those of shipbuilding to those of boiler and pressure vessel manufacturing and further to those of the aerospace industry.

To solve all these problems, various materials for plates (NS 90 is 60 mm thick and 10 Ni 8 Co steel is 100 mm thick) have been manufactured and their properties have been evaluated. They have been used in engineering research that includes molding, heat treatment, welding, and cutting of a full-size semispherical shell. Additionally, disjointing tests have been conducted and property evaluation of parent materials and welded joints have been carried out. The results from these tests have proved that the qualities of these two steels make them the best in the world as materials for the pressure-resistant shell of a bathyvessel and have confirmed the establishment of the required engineering technology. The NS 90 steel, which is in practical use for the pressure-resistant spherical shell of "Shinkai 2000," has shown no abnormality after having been submerged over 200 times.

(4) Ti-6 Al-4 VELI (Titanium Alloy)

At present, metallic titanium is used mainly as a titanium alloy by the aerospace industry in Western countries, taking advantage of its specific strength and heat resistance. In Japan, pure titanium is used for condensers and cooling water tube systems in thermal and nuclear power plants and in chemical plants, taking advantage of its corrosion-resistant properties. On the other hand, titanium alloy is an ideal material for deep sea use because of its specific strength and resistance to seawater. In Japan, pure titanium was used previously in the tube systems of submarines. It is also used in the outer shell framework, pressure equalizing container, and tube system of "Shinkai 2000," but a high strength titanium alloy has been used for the first time in her small pressure resistant container.

Although there are many kinds of titanium alloys, there are two primary kinds suitable for deep-sea use: Ti-6 Al-2 Cb-1 Ta-0.8 Mo, near-α alloy, and Ti-6 Al-4 V, α-β alloy. The former was developed by the U.S. Navy and is a slightly low strength alloy of the 0.2% proof stress 70 kgf/mm^2 class. It has been used in the pressure-resistant shells of "Alvin" and "Sea Cliff." With regard to the latter, the 0.2% proof stress of its annealed material is about 20 percent higher at 84 kgf/mm^2 and the ELI grade, which regulates a penetrant-type impure element to a low level, is suitable for deep-sea use because of its toughness and because it is virtually impervious to seawater. Thus, it has been adopted for the small container of "Shinkai 2000" and more recently for the "Nautile."

Although 10 Ni-8 Co steel has been developed, as mentioned above, as the material for the 6,000 m class bathyvessel, in order to hold its dimension and weight at the levels of Shinkai 2000" Ti-6 Al-4 VELI, which is about 20 percent higher in terms of specific strength, has been selected for use in its pressure-resistant shell. The use of this steel can decrease the bathyvessel's gross weight by more than 10 percent--if one counts the

decreased weight of the buoyant material--over 10 Ni-8 Co steel. When "Shinkai 2000" was built, the production capacity for titanium alloy ingots was inadequate in Japan so this steel was used for the small container. Subsequently, a vacuum melting furnace for large ingots has been built, which should make it possible to use this material in a pressure-resistant shell.

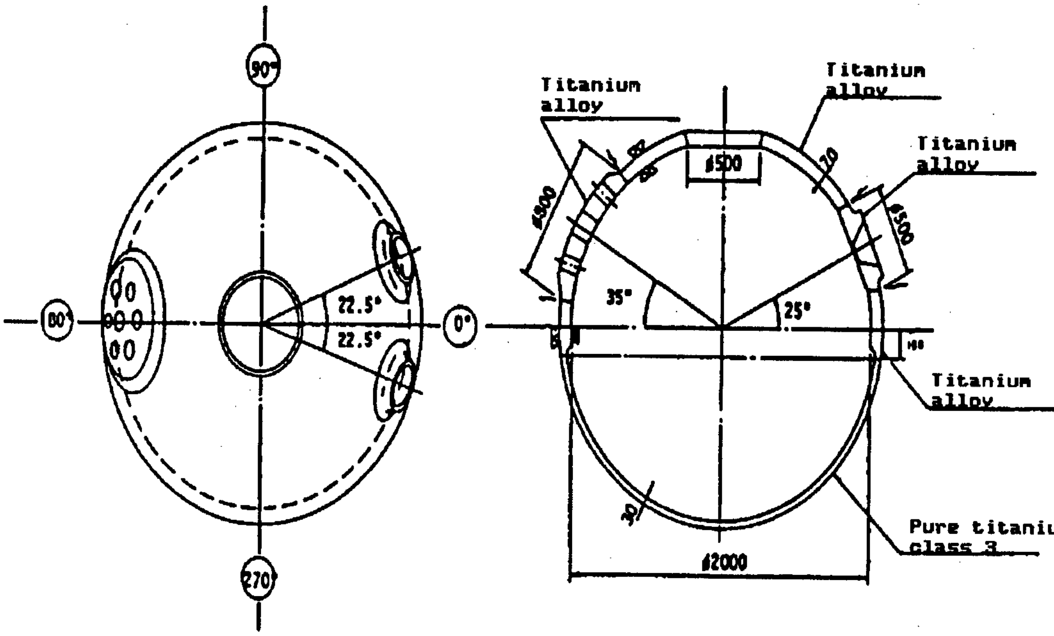

Figure 9. Full-Size Structural Prototype of Pressure-Resistant Shell (Quality used: 6 Al-4 VELI titanium alloy, weight: about 3 t)

The 6,000 m class bathyvessel's pressure-resistant shell will be the largest titanium alloy structure in Japan. The manufacture of a 115 mm thick material and the prototype of a full-size spherical shell structure with an internal diameter of 2 m and a finished thickness of 70 mm (Figure 9) has begun and disjointing tests have been conducted in an attempt to carry out overall research on materials and processing tecnhology and to establish engineering methods for the purpose of putting the shell into practical use. As a result of this research:

(1) Technologies concerning the production of a very thick titanium alloy plate, manufacture of a hot-molded semispherical shell, heat treatment, three-dimensional machining, electron-beam welding and nondestructive tests have been established, and the prototype of a pressure-resistant shell that is close to being a perfect sphere (degree of sphericity 1.003) has been built.

(2) The examination conducted during the disjointing tests of the properties of the parent materials and in the welded zones together with the residual stress has confirmed that all their values are sufficient and that the functional requirements for a pressure-resistant shell are fully met.

For these reasons, this titanium alloy has been determined to be suitable for a 6,500 m bathyvessel's pressure-resistant spherical shell and the manufacture of a real shell with a 2 m internal diameter, an original thickness of 125 mm, and a finished thickness of 73.5 mm is now underway.

3. Development and Practical Use of Buoyant Materials

(1) Buoyant Materials and Their Importance

The maintenance of fair buoyancy in water (buoyant force = weight of fluid displaced) is a basic requirement for a bathyvessel. Although efforts are made to make the pressure-resistant shell spherical to ensure structural efficiency, to make it lighter by using high strength materials and also to lighten all sorts of equipment in accordance with an increased diving depth, it is still impossible to support the gross weight with the inherent buoyancy alone. Thus, a large quantity of buoyant material is necessary to make up for the shortage of buoyant force. Since the weight of the buoyant material accounts for 20-30 percent of the gross weight it is important to develop a buoyant material that will not deform or degenerate under the hydraulic pressure at a maximum diving depth of whose specific gravity is smaller by far than that of seawater.

The required properties of a buoyant material are low specific gravity and pressure-resistant strength that will not diminish under repeatedly applied pressure; the same bulk modulus as seawater; a sufficiently low water absorption rate; noninteraction with seawater; and capable of being molded or cut into any shape. A material called "syntactic foam" has been developed as a buoyant material that satisfies these requirements. This buoyant material is stable. It is made by impregnating very small hollow glass or carbon bulbs (packing material) with resin and then solidifying them. This process makes it possible to produce a buoyant material with a desired specific gravity and strength by properly selecting the specific gravity and strength of the packing material and to raise the packing rate by altering the diameters of the bulbs.

(2) Development of Buoyant Materials

The development of buoyant materials in Japan initially focused on the 6,000 m class and the results of this effort were brought into practical use for the "Shinkai 2000." As a result of further research to upgrade their performance, materials for a 6,500 m bathyvessel have been developed, and those that will be installed on an actual vessel are now under production.

A glass bulb with a diameter of 20-150 μ is the best buoyant material in terms of specific gravity and strength, so the bulb should be selected in accordance with the targeted specific gravity and strength of the buoyant material. Resin, which regulates strength, should be selected from among epoxy resins by taking into account the pressure at the diving depth and its exothermic hardening properties at the time of molding. A vacuum impregnation method was adopted for molding and a packing method that

upgrades the packing rate of the glass bulbs to reduce the specific gravity of the buoyant material was adopted. Additionally, forming conditions were set after investigating the relationship between the method used to impregnate the exothermic hardening resin and the buoyant material's performance. By combining various packing materials with resin--based on these conditions and manufacturing various buoyant materials on an experimental basis--the relationship between the performance of materials and that of buoyant materials (specific gravity, compressive strength, collapsing pressure, compression elasticity coefficient, and water absorption rate) has been clarified.

Also, a nondestructive inspection method for products that use a supersonic crack detector has been established. Based on this research, a large-sized buoyant material was molded and adopted for "Shinkai 2000" after verifying its performance. A glass bulb and a resin with high specific strength were selected for the 6,500 vessel to increase strength. Research to upgrade the packing rate by combining two kinds of glass bulbs with different diameters led to the development of a buoyant material with the same specific gravity as that used for 2,000 m class bathyvessels.

(3) Performance of Buoyant Materials

As buoyant materials for "Shinkai 2000," about 160 pieces of a 600 x 600 x 300 mm rectangular parallelepiped were manufactured and fitted with the ship's body after machining them to the shape and structure of the ship and the equipment. The quantity installed is about 10 m^3 (5.4 t). As basic materials, a glass bulb with a specific gravity of 0.19 and a diameter of 40-50 μ, and an epoxy resin of the bisphenol system with a compressive strength of 15.4 kgf/mm^2 and specific gravity of 1.23 were used. With respect to the main properties of the buoyant material, its specific gravity is 0.537, collapsing pressure 710 kgf/cm^2, compression elasticity coefficient 257 kgf/mm^2, and water absorption rate 0.44 percent. This buoyant material has already been used in submerged cruises over 200 times without suffering any abnormality at all.

For the buoyant material developed for a 6,000 m bathyvessel, based on this track record and aiming at the same specific gravity despite a triple diving depth, the packing rate was improved by using combinations of two kinds of glass bulbs with a specific gravity of 0.28 and different diameters (-44 μ, -149 μ), and for the necessary resin an alicyclic epoxy resin with a compressive strength of 26 kgf/mm^2 a specific gravity of 1.24 was used. As a result, a high performance buoyant material with a specific gravity of 0.541 (the same as that for the 2,000 m class), a collapsing pressure of 1,330 kgf/cm^2, a compression elasticity coefficient of 335 kgf/mm^2, and a water absorption rate of 0.23 percent was obtained. This material will be put to practical use in the 6,500 m bathyvessel.

As mentioned above, a buoyant material is indispensable for a bathyvessel. At the same time, it is a useful material that can be put to extensive use for recoverable machines installed on seabeds and observation machines requiring fair buoyant force in accordance with depth.

4. Conclusion

Component materials for high performance bathyvessels and marine observation machines that operate under the very severe environmental conditions of seabeds should be developed by giving consideration to the close interrelationship of the properties of basic materials and design and engineering technologies. Although materials for a 6,500 m bathyvessel are already in the stage of practical use, the development of high performance materials for use in regions deeper than 10,000 m will become an important task for the future.

20110/9365

VLSI **Production, Test Equipment**

43065031 Tokyo DENSHI ZAIRYO BESSATSU in Japanese Nov 87 pp 1-238

[Excerpts]

Table 7. Estimation of Semiconductor Production Equipment Market in Japan (Number of samples: 48)

	1986	1987	1988	1989	1990
Average value (¥100 million)	3,020.7	3,213.0	4,034.1	4,422.3	4,781.0
Market growth compared to last year (percent)	--	6.4	25.6	9.6	8.1
Average growth (percent)			12.2		
Minimum value (¥100 million)	2,000	2,270	2,900	3,000	3,200
Maximum value (¥100 million)	4,000	4,500	5,500	5,700	7,000

(Source: SEAJ)

Table 8. Estimation of Semiconductor Production Equipment Sales in Japan (Number of samples: 48)

	1986	1987	1988	1989	1990
Average value (¥100 million)	2,811.2	3,076.3	3,843.0	4,344.2	4,638.8
Market growth compared to last year (percent)	--	9.4	24.9	13.0	6.8
Average growth (percent)			13.3		
Minimum value (¥100 million)	2,000	2,000	2,600	2,700	2,700
Maximum value (¥100 million)	3,900	4,300	5,000	6,000	7,000

(Source: SEAJ)

Table 9. Percentage Ratio of Semiconductor Production Equipment Export Sales Vs. Sales in Japan (Number of samples: 53)

	1986	1987	1988	1989	1990
Average value (%)	15.2	15.8	16.9	17.5	18.9
Minimum value (%)	7.0	10.0	9.0	9.0	10.0
Maximum value (%)	22.0	23.0	25.0	25.0	30.0

(Source: SEAJ)

Table 10. Estimated Percent Ratio of Japanese Semiconductor Production Equipment Import (Number of samples: 54)

	1986	1987	1988	1989	1990
Average value (%)	14.8	14.8	12.8	12.9	12.2
Minimum value (%)	9.0	8.8	7.6	7.5	7.4
Maximum value (%)	30.0	30.0	28.0	30.0	26.0

(Source: SEAJ)

Table 11. Estimation of When Japanese Semiconductor Production Equipment Market Will Rally (Number of sample: 60)

Selected item	Number of samples	
a. 1987, 1st quarter	0	(0.0%)
b. 2d quarter	5	(8.3%)
c. 3d quarter	11	(18.3%)
d. 4th quarter	17	(28.3%)
e. 1988 1st quarter	10	(16.7%)
f. 2d quarter	9	(15.0%)
g. 3d quarter	4	(6.7%)
h. 4th quarter	4	(6.7%)
Total	60	

(Source: SEAJ)

Table 2. Major Specifications of 60 Kg-Class Commercial Drawing Equipment

Item		Kokusai Denki	Kayex Hamco	Leybold Heraeus	Ferrofluidics
Type		DP-3800RW	CG-6000	EKZ-2700	6-4-2
Performance	Volume of filling (max) (kg)	60	60	60	60
	Crucible diameter	16"ϕ	16"ϕ (18"ϕ possible)	16"ϕ	16"ϕ
	Crystal diameter	5~6"ϕ	5~6"ϕ (8"ϕ possible)	5~6"ϕ	5~6"ϕ (8"ϕ possible)
	Crystal drawing stroke (mm)	1,700 (2,300)	1,800 (2,489)	2,700	1,550 (2,032)
	Diameter precision (mm)	±2	±1	—	±1
Crystal drawing method		Wire winding	Wire winding	Mobile shaft for wire winding	Ball chain
Type and dimension	Main chamber type	Mobile cylinder	Mobile cylinder	Mobile cylinder	Fixed cylinder
	Upper chamber type	½ ellipse, mobile	Conic, mobile (Chamber shared by drawing chamber)	½ ellipse, mobile (Chamber shared by drawing chamber)	½ ellipse, mobile (Chamber shared by drawing chamber)
	Drawing chamber type	Mobile cylinder (with crystal storage basket)	Mobile cylinder (with crystal removal door)	Mobile cylinder (with crystal removal door)	Mobile cylinder
	Chamber inner diameter x height	800mmϕ × 1040mmH	760 × mmϕ × 1085mmH	800mmϕ	857mmϕ × 1041mmH
	Inner diameter of drawing chamber (mmϕ)	320 (Storage basket inner diameter 220)	254	300	241
	Gate valve: Inner diameter (mmϕ)	220	178	300	184
	Gate valve: Type	Vertical, door type	Vertical, door type	Horizontal, swing type	Horizontal, swing type
	Equipment height (mm)	5,500 (6,000)	— (6,800)	6,850	4,570 (—)
Main sensors	Seed touching	Not available	Yes	Yes	Yes
	Diameter measurement	ITV image processing	Line scanning camera	Line scanning camera	Line scanning camera
	Liquid surface temperature	Optional	Yes	Yes	Yes
	Liquid surface position	Not available	Not available	Yes	Optional
	Heater temperature	Pyrometer	Pyrometer	Pyrometer	Pyrometer
	Crystal weight	Yes (sensitivity: 100 g)	Yes (sensitivity: 100 g)	Not available	Not available
Extent of automation		Only for linear barrel	Vacuum drawing to cooling	Vacuum drawing to cooling	Vacuum drawing to cooling

Table 1. Major Specifications of Medium Current Ion Injector

Manufacturing/marketing company / Model / Item	Tokyo Electron (Varian/Extrion, TEL/Varian)		Marubeni Hi-Tech (EATON/NOVA)	Nishin Electric	Nihon Vacuum
	300XP	2000SJ	NV-6200	NH-20SD	IMM-2200C
Acceleration voltage (kV)	10~200	10~200	5~200	10~200	10~200
Maximum beam current (mA) $^{11}B^+$	0.6	0.6	1.0	0.6	0.6
$^{31}P^+$	1.5	1.5	1.7	1.0	1.5
$^{75}As^+$	1.5	1.5	1.5	1.0	1.2
Maximum wafer diameter (inches)	6	6	6	6	6
Processing speed (wafers/time) (10 second injection)	250	200	250	330	300
Injection angle	0, 3, 5, 7° Variable	0~20° Variable	0~30° Variable	0~30° Variable, rotary	0~10° Variable
Injection chamber	Dual	Single	Single-dual platten	Dual	Dual
Wafer transport system	Blade-up	Moving fork	Swing arm	Belt drive	Belt and swing arm

Table 2. Major Specifications of Large Current Ion Injector

Manufacturing/Marketing company / Model / Item	Sumitomo Eaton-Nova/Marubeni Hi-Tech (SEN, EATON/NOVA)		Tokyo Electron (TEL/Varian, Extrion)	Nisshin Electric	Nihon Vacuum	Hitachi Manufacturing	AMT Japan (AMT)
Model	NV-10SD-80/160	NV-20-200	80/120/160XP	PR-80	IMH-2200	IP-825A	PRECISION 9000
Acceleration voltage (kV)	5~80, 160	5~200	10~80/120/160	5~80	5~200	20~120	10~180
Maximum beam current (mA)							
$^{11}B^+$	5.0	8.0	6.0	5.0	6.0	6.0	11.0
$^{31}P^+$	15.0	20.0	10.0	13.0	15.0	12.5	30.0
$^{75}As^+$	15.0	20.0	10.0	13.0	12.5	12.5	30.0
Wafer diameter-sorted batch size							
5"ϕ (per wafer)	20	20	13	15	13	13	25
6"ϕ	17	15	13	13	13	10	25
8"ϕ	12	10	8	-	-	-	17
Processing time (wafers/time) (6"ϕ, $5\times10^{15}/cm^2$)	~110	~130	~135	~100	~120	~97	~200
Injection angle	0°, 7°	0°, 7°	0°, 7°	0°, 7°	0~10°	0, 7.5°	0°, 7°
Injection chamber	Single	Single	Dual	Dual	Single	Dual	Single
Wafer transport system	Moving arm	Moving arm	Moving fork	Belt	Moving arm	Belt and moving arm	Blade-up

Table 1. Comparison of Lamp Annealer by Different Manufacturers

Manufacturer / Unit name	AG Associates HEATPULSE 2146	Dai-Nihon Screen LAW-612-A (-LP)	Peak System ALP-6000 (-8500)	Varian RTP8000	Koyo Lindburg RLA-6100(SV)	Eaton ROA-500
Source lamp	Tungsten halogen lamp	Tungsten lamp	AC arc lamp	Tungsten lamp	Tungsten halogen lamp	DC arc lamp
Number of lamps	Upper 10 Lower 11	Upper 14 Lower 14	Upper 1	Upper 18	Upper 20~30 Lower 20~30	Upper 1
Illuminated plane	Both planes	Both planes	Single plane	Single plane	Both planes	Single plane
System for uniform temperature distribution	Reflection plate designed	Lamp power-zone control	Reflection plate designed	Reflection plate designed	Lamp power-zone control	Reflection plate designed
Temperature measurement	Pyrometer (3.5μm) or TC	TC	Pyrometer(5μm)	Pyrometer (4.8~5.2μm)	Pyrometer (5μm)	Pyrometer
Temperature control	Closed loop	Psuedo-closed loop	Closed loop	Closed loop	Closed loop	Closed loop
Chamber material	Quartz tube	Quartz tube	SUS316	Aluminum (SUS304)	Quartz tube	Aluminum
Wafer diameter	3"~6"	3"~6"	3"~6"	2"~8"	2"~6",8" Can be used for 8"	2"~6",8" Can be used for 8"
Handling robot	Robot and belt } Both used	Quartz arm	Robot	Robot	Quartz arm	Quartz arm
Vacuum outlet	Not available	Not available (available)	Not available (available)	Available	Not available (available)	Available
Vacuousness (Torr)	—	— (10^{-6})	— (5×10^{-4})	10^{-3}~10^{-5}	$(10^{-3}$~$10^{-4})$	10^{-2}
Source voltage	200V3φ	200V3φ	200V3φ	200V3φ	200V3φ	200V3φ
Maximum consumption current, power	70A	58kVA	40kW	45kW	60kVA	160kVA
Dimensions (W×D×H, mm)	915×970×1,200	1,480×1,100×1,100	965×1,721×1,423	1,500×1,280×1,800	1,300×1,200×2,100	1,829×1,676×1,588
Usable gas	O_2, N_2, Ar, HCl, NH_3, Forming gas	O_2, N_2, Ar, HCl, NH_3	O_2, N_2, Ar, HCl, NH_3	O_2, N_2, Ar, (HCl, NH_3)	O_2, N_2, Ar, HCl, NH_3, H_2, PH_3, etc.	O_2, N_2, Ar
Miscellaneous	HEATPULSE 2106 with inert gas only; HEATPULSE 2126 for low-temperature sintering available	() indicates the model with vacuum pumping system	() indicates the model with vacuum pumping system	() indicates the model with reactive gas treatment system	() indicates the model with vacuum pumping system	Modification for reactive gas treatment system is available

Table 1. Features of Different Dry Etching Techniques

	Barrel plasma etching	Blanar plasma etching	Chemical dry etching	Reactive ion etching	Reactive ion beam etching	Ion milling	RF sputtering etching
Reaction mechanism	Chemical	Chemical/ physical	Chemical	Chemical/ physical	Chemical/ physical	Physical	Physical
Sample position (with respect to the plasma)	In contact	In contact	Separated	In contact	Separated	Separated	In contact
Pressure (Pa)	10~100	10~100	10~100	1~50	0.1~1	0.1~1	0.1~1
Selection ratio (general)	Isotropic	Isotropic/ anisotropic	Isotropic	Anisotropic	Anisotropic	Anisotropic	Anisotropic
(SiO_2/Si)	Large Small	Large Medium	Large Small	Medium Medium	Medium Medium	Small Large	Small Large
Reaction gas	O_2, CF_4+O_2	$C_2F_6+CHF_3$ CCl_4	CF_4, CF_4+O_2	CHF_3+O_2 CCl_4, BCl_3	C_3F_8, CCl_4	Ar	Ar
Etching materials	Si, Si_3N_4 Polycrystal Si	SiO_2 AlSi	Si, Si_3N_4 Polycrystal Si	SiO_2, PSG Al, AlSi	SiO_2 AlSiCu	SiO_2	SiO_2

Table 2. Problems With Regard to Micro-Fabrication

Problem	Mechanism	Comment	Description of defects
Surge	∘Charges stored in RF power supply unit and blocking capacitor cause breakdown of oxidized coating and generation of sparks between Al electrodes	∘Limited to case where wafer is placed on top of RF power supply unit	∘Defective insulation of oxidized coating ∘Short-circuited Al electrodes
Contamination	∘Contamination caused by C, F, or heavy metals which migrate from the resist, etching gas, or from inside instrument	∘There is concern about contamination due to C or F when anisotropy is to be achieved by means of side-wall protection coating ∘Difficult to remove resist after ion injection ∘Innovation for system structure design needed	∘Increase in contact resistance ∘V_T shift, and lowering of g_m ∘Lowering of h_{FE} variation and pressure resistance
Damage	∘Ultraviolet, soft X-ray, and high energy ions cause damage to the crystalline structure, and generate charges and traps	∘Even hard ultraviolet rays cause damage	∘Increase in contact resistance ∘V_T shift, and lowering of g_m ∘Lowering of h_{FE} variation and pressure resistance
Precision	∘Depending on state of progress in etching, etching characteristics change ∘Promoting to diversify type of coating, and switch to thin of thick film protection	∘Needs an etching condition appropriate to process and device	∘Lowering of yield

Table 3. Widely Used Dry-Etching Systems

Manufacturer	Name of system	Method	Etching material	Features
(Batch-type system)				
AMT	PE8300 series	Hexsode RIE	SiO_2, Al, Poly-Si	18 sheets/ batch (6")
Nihon Electric Anelva	ILD-4013	RIE	SiO_2, Al, Poly-Si	8 sheets/ batch (6")
(Pine-needle type system)				
Tokyo Applied Chemical	OAPM 406	Plasma	Poly-Si, SiN	Anode/cathode switching available
Tokyo Electron	TELETCH 480	Plasma	Poly-si, SiN	Variable spacing between electrodes
	580	Narrow gap	SiO_2	"
	680	RIE	Al	"
Plasma system	PE 825	Plasma	Poly-Si, SiN	Anode/cathode switching available
Perkin-Elmer	OMNITECH	Plasma	SiO_2, Poly-Si Al	Stripper chamber 2
Plasma Therm	A 360	RIE	Al	3 chambers
Alchem Tech	GIR 260	RIE	Poly-Si, SiO_2	2 chambers
Varian	ZYLIN 200	RIE	Al	3 chambers
Tegal	1500	Triode	Si, SiO_2, Al	Dissimilar frequency RF power supply superimposed
GCA	606/616	Triode	SiO_2, Al	RF power time-sliced and superimposed
Nippon Electric Anelva	ILD-4031	Narrow gap	SiO_2	
	MERIE	Magnetron	Al, SiO_2	Rotary magnetic field
Tokuta Manufacturing	HiRRIE-100	RIE	Al	Post-rinsing treatment
	HiRRIE-II/500	Magnetron	SiO_2, Al	Magnet scanning
MRC	ARIES	Magnetron	Si, SiO_2	Fixed magnetic field
Hitachi Manufacturing	M 206A	ECR	Poly-Si, Si	Variable RF bias

Table 2. List of Widely Used Sputtering Systems

System type (Manufacturer, Sales representative)	Wafer processing	Chamber organization	Sputtering	Pump	RF etching	Substrate heating	Bias sputtering	Film materials	Through-put
MCH-9800 (Nihon Vacuum Technology)	Cassette-to-cassette 5", 6" single slice	Independent 1 Etching 3 Sputtering 3 Target	Side	Cryo	High heat etching	Quartz lamp	RF/DC	Multi-layer reactive sputtering Al, High boiling temperature metal silicide	40 wafers/hr
ILC-1015 (Nippon Electric Alneva)	Cassette-to-cassette 5", 6" single slice	Fully independent 1 Etching 1 Separation 3 Sputtering 3 Target	Side	Cryo	High heat etching	Quartz lamp	RF	Multi-layer reactive sputtering (TiN/Al) High boiling temperature metal silicide	50 wafers/hr
VARIAN 3280 (3290) (VARIAN, Tokyo Electron)	Cassette-to-cassette 5", 6" single slice	1 Sputtering 1 Etching 2 (3) Target	Side	Cryo	Normal rate etching	Gas-heat conduction	DC	Al, Al-alloy high boiling temperature metal silicide, Al leveled	45 wafers/hr
ECLIPSE (MRC, Nihon MRC)	Cassette-to-cassette 4", 5", 6", 8" single slice	Fully independent 1 Etching 2 (3) Sputtering 2 (3) Target	Side	Cryo	Normal rate etching	Gas-heat conduction	RF	Multi-layer reactive sputtering (TiN) Al leveled high boiling temeprature metal silicide	60 wafers/hr
HORIZON (GRYPHON, MBK Microtech)	Cassette-to-cassette 4", 5", 6" batch	1 Etching 1 Sputtering 3 Target	Side	Cryo Ti getter Meissner	Ion beam etching	Resister heating	DC	Multi-layer Co-deposition reactive sputtering (TiN/Al) Al leveled	50 wafers/hr
SYPER LINE (MTI, Nigata MTI)	Cassette-to-cassette 4", 5", 6", 8" single slice	Independent 1 Etching 1 Separation 2 Sputtering 4 Target (2 target 1 sputtering)	Side	Cryo	Normal rate etching	Quartz heating carrier plate	DC/RF	Multi-layer, Al leveled Al-alloy high boiling temperature metal silicide	40 wafers/hr
SWS 605/606 (BALZARS, Hakuto)	Cassette-to-cassette 4", 5", 6" inline	1 Etching 1 Sputtering 2 Target	Side	Cryo Meissner	Normal rate etching	Quartz lamp	DC/RF	Al, Al-alloy Ti : W/Al silicide	90 wafers/hr

Table 2. Comparison of Functions According to Dye-Bonder Manufacturer Catalogs

Manufacturer / Model / Item	Shinkawa	Toshiba Precision Machinery		Nippon Electric Machinery
	SPM-FA-PA10.2	FED-1000FAM	ED-702DFAM	CPS-100
Bonding head	Digital	Digital	Cam	Digital
Bonding method	Epoxy	Epoxy	Epoxy	Epoxy
Bonding speed (s/P)	0.8	0.8	0.58	0.48
Bonding precision XM (mm)	±0.1 ±2°	±0.1 ±3°	±0.1 ±2°	±0.1 ±3°
Dye size (mm)	□0.8-□7.0	□2.0-□8.0	□0.8-□7.0	□1.0-□8
Wafer size (mm)	ϕ6	ϕ6	ϕ6	ϕ8
Paste supply	Dispense	Dispense	Dispense	Dispense
Dye supply	Tray/wafer	Tray/wafer	Tray/wafer	Wafer
Frame supply	Stacking/ magazine	Stacking	Stacking	Stacking
Frame storage	Magazine	Magazine	Magazine	Magazine
Detection system	ITV GO/NG	ITV GO/NG	ITV GO/NG	ITV GO/NG
Feeder mechanism	Universal	Flexible		Flexible
Production control information	Available	Available	Available	Available
Installation area (m)	900x900	1,000x1,000	1,30x800	1,000x 1,000
Weight (kg)	620	500	450	450

[continued]

[Continuation of Table 2. Comparison of Functions According to Dye-Bonder Manufacturer Catalogs]

Manufacturer / Model / Item	Kyushu Matsushita DA1302	K & S 6300	Kaijo Electric FDB10E
Bonding head	Cam	Digital	Cam
Bonding method	Epoxy	Epoxy twin crystal	Epoxy
Bonding speed (s/P)	0.5	0.75	1.6
Bonding precision XM (mm)	±0.1 ±2°	±0.038 ±1°	±0.075 ±1°
Dye size (mm)	□ 1- □ 8	□ 1.02- □ 12.7	□ 0.7- □ 2.4
Wafer size (mm)	ϕ6	ϕ 5	ϕ 4
Paste supply	Stamping	Stamping	Stamping
Dye supply	Tray/wafer	Tray/wafer	Tray/wafer
Frame supply	Stacking	Stacking/ magazine	Stacking
Frame storage	Magazine	Magazine	Magazine
Detection system	ITV GO/NG	ITV GO/NG	ITV GO/NG
Feeder mechanism			
Production control information	Available	Available	
Installation area (m)	1,040x1,090	1,320x965	1,000x1,000
Weight (kg)	550	408	400

Table 1. Comparison of Different Wire Bonding Methods

Bonding method	Thermo compression	Ultrasonic	Thermo sonic
Bonding type	Nail head bonding	Ultrasonic wedge bonding	Ultrasonic ball bonding
Wire used	Au wire ϕ18- 50 μm	Aj wire (partly, Au wire) ϕ18 - 500 μm	Au wire (partly Al, Cu wires) ϕ15 - 50 μm
Bonding tool	Capillary (ruby, ceramic, silicon nitride)	Wedge (WC, TiC)	Same as in thermo compression
Bonding factor	∘Temperature (280-400°C) ∘Compression ∘Time	∘Ultrasonic wave amplitude ∘Compression ∘Time	∘Temperature (70-250°C) ∘Ultrasonic wave amplitude ∘Compression ∘Time
Bonding procedure	∘Plastic flow due to thermo compression	∘Plastic flow and local frictional heat due to compression ∘Local melting ∘Mutual spreading	Advantages of thermo compression and ultrasonic methods are utilized
Features	∘Absence of bonding orientation ∘Sensitive to degree of surface cleanness	∘Does not require heating ∘Bonding orientation can be set ∘Small bonding area	∘Can bond at low temperature and low compression ∘Insensitive to degree of surface cleanness
Application	General IS, LSI	Highly reliable components (IC, LSI, VLSI, hybrid)	General IC, LSI, hybrid IC

Table 2. Comparison of Main Characteristics of TS Bonders

Manufacturer	Shinkawa	Kaijyo Electric	K&S	Toshiba Precision Machinery	Hitachi Tokyo Electronics
Model	SWB-FA-UTC-40	FB-107	1482	HN-901FAB	AUTAS-230-TS
Head driving mechanism	DC servo	DC servo	DC servo	DC servo	Linear motor direct
Bonding speed (second/wire)	0.2 (2mm loop)	0.2 (2mm loop)	0.14 (1.5mm loop)	0.2 (2mm loop)	0.17 (2mm loop)
Overall precision of bonding (μm)	±5 (X8)	±6.2 (X8)	±12.7 (X4.3)	±10 (X3.5)	±10
X-Y resolution (μm)	2.5	2.5	2.54	2	5
Sensor resolution (μm)	3.7 (x8 ITV)	3.7 (x8 CCD)	6.3 (x4.3 CCD)	5 (x3.5 CCD)	3.75 (x7.3 CCD)
Sensor speed (s)	0.25/2 pieces	0.25/2 pieces	0.31/2 pieces	0.45/2 pieces	0.5/2 pieces
Size of usable wire (μm)	20-50	18-38	25-38	25-50	25-38
Work stage	Flexible	Flexible	Flexible	Flexible	Flexible
External communication	RS232C	RS232C	RS232C	RS232C (Optional)	RS232C (Optional)
Equipment size (W x D mm)	700 x 700	800 x 820	838 x 940	700 x 800	700 x 750
Note	Each lead readjustable	Each lead readjustable	Each lead readjustable	Each lead readjustable	Each lead readjustable

Table 3. Comparison of Main Characteristics of US Bonders

Manufacturer	Shinkawa	Ultrasonic Industry	Ultrasonic Industry	K&S
Model	SWB-FA-US-30	UWB-101	UWB-201/301 (thick wire)	1471
Bonding head type	Digital	Digital	Digital	Digital
Bonding speed (second/wire)	0.29 (2mm30°)	0.25 (2mm separation 0)	0.8 (6mm separation 0)	0.2 (2mm)
Overall precision of bonding (μm)	±10 (compression marks)			±12.7
X-Y resolution (μm)	2.5 (head moving)	4 (work frame moving)	4 (work frame moving)	2.54 (head moving)
Angular resolution (°)	0.45	0.18	0.18	0.007
Sensor resolution (μm)	3.7	3.1	8.4	3.75
Sensor speed (s)	0.25/2 pieces	0.2/1 pieces	0.2/1 pieces	0.31/2 pieces
Size of appropriate (μm)	25-50	25-80	100-300/ 300-600	17.8-76.2
Bond area (mm)	20 x 20	104 x 104	104 x 104	25.4x25.4
Equipment size (W x D mm)	900 x 700	695 x 705	695 x 705	1041 x 965
Note			∘Pull test function ∘Loop forming mechanism ∘S-shaped bonding mechanism	

Table 1. Widely Used Random Logic LSI Testers

	T3381	DIC-9035B	J953	Micromaster	Mega One	GR-170	T3342	DIC-8035C	T3320	DIC-8034
Test frequency (MHz)	100	50	50	40	40	40	40	40	20	20
Multinode test frequency	200	200 (4 pin multiple)	100	80	80	80	-	-	-	—
Number of pins	~512	~512	~256	~256	~256	~288	~256	~256	~256	256
Overall precision of timing (ns)	±0.5(AG) ±0.4(AE)	±1.0(CMOS) ±0.5(Bip)	±0.5	±0.5	±0.7	±0.75	±0.9	±1.6	±1.4	±2.4
Timing phase number	64 edge	~46 edge	(Par pin)	(Par pin)	(Par pin)	~16	40 edge	~36 edge	24 edge	25 edge
Voltage level (V)	-4~+9(AG) -2.5~0(AE)	-2~+7(CMOS) -2~+3(Bip)	-3~+8	-2~+6.5	-2~+8	-2~+13.5	-4~+9	-2~+10	-2~+8	-2 +10
Driver output resistance/ Comparator capacitance	100Ω/30pF(AG) 50Ω/ (AE)	100Ω/35pF(CMOS) 50Ω/55pF(Bip)	50Ω/30pF	93Ω/26pF(CMOS) 50Ω/37pF(BIMOS)	/90pF	90Ω	/30pF	50Ω/	50Ω/	50Ω
Minimum pulse width (ns)	4.5(AG) 1.5(AE)	5(CMOS) 2(Bip)	5	5	6	6	4.5	8	10	10
Number of general purpose DC testers	~4	~16	~2	~4	4	1	1	~8	1	4
Number of sub DC testers	~32	1/pin	1/pin	1/4 pin	1/pin	-	~16	-	~16	—
Pattern memory size (W)	256k	~512k	4M~16M	~4M	1M	256k	64k	64k	64k	64k
Large size buffer memory	~64MB	~64MB	-	-	-	-	~64MB	~8MB	16MB	8MB
Computer	Dedicated processor (32bit)	68020	SUN-3	68020	Multiprocessor based on 68010	Dedicated processor (32bit)	Dedicated processor (32bit)	Dedicated processor (16bit)	Dedicated processor	Dedicated processor (16bit)
For engineering application	General purpose processor (32bit)	VAX8250	SUN-3	APOLLO EWS		PDP11/84	General purpose processor (32bit)	ECLIPSE-S140	-	General purpose processor (16bit)
Tester language	Dedicated language	Dedicated language PASCAL	Dedicated language (Based on C)	PASCAL	PASCAL	PASCAL	Dedicated language	Dedicated language	Dedicated language	Dedicated language
Manufacturer	Advantest	Ando Electric	TERADYNE	TRILLIUM	MEGATEST	Tel-Dunrad	Advantest	Ando Electric	Advantest	Ando Electric

Table 1. Comparison of Functions of Widely Used Memory Testers (Part 1)

. Model / Manufacturer	T3333 Advantest	T3581 (Advantest)	J 386-10 (Teradine)	J 937 (Teradine)	DIC-8046 Ando Electric	DIC-8043 Ando Electric	7600/32	9500 Minato Electroni
. Devices to be tested	DRAM, SRAM, ROM	DRAM, SRAM, ROM VRAM, FIFO, DUAL PORT Memory	DRAM, SRAM, ROM	DRAM, SRAM VRAM, FIFO, DUAL PORT Memory	DRAM, SRAM, ROM VRAM, FIFO, DUAL PORT Memory, etc	DRAM, SRAM, ROM VRAM, FIFO, DUAL PORT Memory, etc.	DRAM, SRAM, ROM	DRAM, SRAM, ROM
. Testing speed (MHz)	30	100	20	50	60	40	25	25
. Overall timing precision	±1.1 or less	±0.7 or less	±1.25	±0.75	±0.8 or less	±1.1 or less	±1.1 or less	±0.9 or less
(1) Comprehensive driver	±0.6	±0.35	±0.75	±0.30	±0.4	±0.4	±0.6	±0.4
(2) Comprehensive comparator	±0.5	±0.35	±0.50	±0.15	±0.4	±0.4	±0.5	±0.5
. Test station	2	2	2	2	2	2	2	2
(1) Pin arrangement (Total pins)	320	160	64	212	280	280	528	256
a. Driver pins	32Dr×8	30Dr×4	Address 40, Clock16	ADRS112, Clock 64	136Dr	136Dr	384Dr	192Dr
b. I/O pins	16I/O*4	40I/O	8I/O	36I/O	144I/O	144I/O	144I/O	64I/O
(2) Number of parallel measurements (No/ST)	16	8	4	8	8	8	16	8
. Test processor	TP-1	TP-1	M365	SUN-2 (68010)	ECLIPSE S-120	ECLIPSE S-120	RX-11/23	RX-11/23
Main memory/Data width	2 Mbyte/32bit	2 Mbyte/32bit	256kbyte/18bit	4 Mbyte/16~32	2 Mbyte/16bit	2 Mbyte/16bit	512kbyte/16bit	512kbyte/16bi
. Timing generator (TG)	Single TG	Double TG	Single TG	Single TG	Double TG	Double TG	Single TG	Single TG
. (1) Test cycle	1.048ms~32ns	16ms~10ns	4 ms~50ns	6.5μs~20ns	4 ms~16ns	4 ms~16ns	4 ms~40ns	4 ms~40ns
Resolution	1 ns	125ps	1 ns	100ps	500ps	500ps	2 ns	2 ns
(2) Clock number (edge)	24	36	22	24	32	32	20	20
Resolution (ps)	125	31.25	100	100	100	100	100	100
(3) Strobe number (edge)	2	4	2	2	3	3	2	2
Resolution (ps)	125	31.25	100	100	10	10	100	100
(4) RTTC function (set)	16	1024	16	256	16	16	16	16
Pattern generator (PG)	Single PG	Double PG	Single PG	Single PG	Double PG	Double PG	Single PG	Single PG
(1) Micro-instruction	128bit ×1k word	128bit ×1k word	72bit ×64 word	220bit ×256 word	160bit ×1k word	160bit ×1k word	86bit ×2k word	86bit × 2kwor
(2) Address generation (bit)	X=12, Y=12, Z=8	X=12, Y=12, Z=8	X=10, Y=10	X=12, Y=12	X=14, Y=14	X=14, Y=14	X=12, Y=12	X-12, Y-12
(3) Data generation (bit)	18	18	8	18	36	36	9	8
(4) Address scramble	4k word×12 bit ×2 256word ×8bit	4k word×12 bit ×2 256word ×8bit	1k word×10 bit ×2	4k word×12 bit ×2	4k word×12 bit ×2	4k word×12 bit ×2	4k word×12 bit ×2	4kword × 12bi x2

Table 1. Comparison of Functions of Widely Used Memory Testers (Part 2)

Model / Manufacturer	T3333 Advantest	T3581 Advantest	J386-10 Teradine	J937 Teradine	DIC-8046 Ando Electric	DIC-8043 Ando Electric	9600/32 Minato Electronics	9500 Minato Electronics
Memory for defect analysis (size)	30MHz: 4 Mbit	100MHz: 1 Mbit × 4	20MHz: 1 Mbit × 2	50MHz: 4 Mbit	60MHz: 8 M bit	60MHz: 8 M bit	25MHz: 4 M bit	25MHz: 4 bit
Power units for devices to be tested (units/ST)	12	12	4	8	11	11	49	25
(1) Output voltage/resolution	0~±35V/2mV	0~±35V/2mV	0~±20V/10mV	0~±20V/10mV	0~±35V/1mV	0~±35V/1mV	0~±20V/10mV	0~±20V/10mV
(2) Current measurement/resolution	0~±500mA/2nA	0~±500mA/2nA	0~±500mA/	0~±1A/1µA	0~±500mA/1nA	0~±500mA/1nA	0~±500mA/1nA	0~±500mA/a nA
Measurement precision	±(0.5% + 3LSB)	±(0.5% + 3LSB)	±(1% + 50µA)	±(0.15% + 3µA)	±(2% + 5nA)	±(2% + 5nA)	±(0.5% + 8nA)	±(0.5% + 8 nA
DC test unit	4 units/ST	4 units/ST	1 unit/ST	2 units/ST	4 units/ST	4 units/ST	16 units/ST	8 units/ST
(1) Superimposed voltage resolution	0~±40V/0.5mV	0~±40V/0.5mV	0~±100V/1mV	0~±40V/1mV	0~±40V/1mV	0~±40V/1mV	0~±30V/1mV	0~±30V/1 mV
Current measurement/resolution	0~±300mA/2nA	0~±300mA/2nA	0~±200mA/1nA	0~±200mA/1nA	0~±400mA/100pA	±400mA/100pA	0~±500mA/1nA	0~±500mA/1 nA
Measurement precision	±(0.5% + 6nA)	±(0.5% + 6nA)	±(0.3% + 15nA)	±(0.3% + 20nA)	±(0.5% + 6nA)	±(0.5% + 6nA)	±(0.5% + 8nA)	±(0.5% + 8 nA)
(2) Superimposed current resolution	0~±300mA/2nA	0~±300mA/2nA	0~±200mA/1nA	0~±200mA/1nA	~±400mA/100pA	±400mA/100pA	0~±500mA/1nA	0~±500mA/nA
Voltage measurement/resolution	0~±40V/0.5mV	0~±40V/0.5mV	0~±100V/1mV	0~±40V/1mV	0~±40V/1mV	0~±40V/1mV	0~±30V/1mV	0~±30V/1 mV
Measurement precision	±(0.1% + 2mV)	±(0.1% + 2mV)	±(0.15% + 3mV)	±(0.15% + 3mV)	±(0.1% + 2mV)	±(0.1% + 2mV)	±(0.15% + 5mV)	±(0.15% + 5 mV)
Driver (level selection)	4	8	2	2	4	4	4	4
(1) Output voltage (VIH·VIL)	−5~12V	−4~9V	−5~7.5V	−4~8V	−3~8V	V−3~8V	−2.5~7.5V	−2.5~7.5V
(2) Through rate	3.5ns/3Vp-p	2.0ns/3V	5.0ns/2V	1.5ns/2V	3.0ns/3V	3.0ns/3V	3.0ns/3V	2.4ns/3 V
(3) Minimum pulse width (ns)	7.0ns/3Vp-p	4.5ns/3V	10ns/3V	5.0ns/3V	4.0ns/1.5V	4.0ns/1.5V	6.0ns/3V	6.0ns/3 V
(4) Output impedance (Ω)	75±10	50±5	95±9.5	50±5	93±5	93±5	Approximately 75	Approximately 50
(5) Over-/Undershoot	±(3% + 100mV)	±(5% + 100mV)	≤3% or ≤150mV	≤(5% + ≤30mV)	±(5% + 50mV)	±(5% + 50mV)	±(5% + 50mV)	
Comparator (level selection)	2	8	2	2	2	2	2	2
(1) Input voltage (VOH/VOL)	−3~10V	−4~9V	−4.5~4.5V	−2.5V~8V	−3~8V	−3~8V	−5~7V	−5~7 V
Precision of reference voltage	±(1% + 30mV)	±(1% + 20mV)	±(0.2% + 50mV)	±(0.25% + 20mV)	±(0.1% + 10mV)	±(0.1% + 10mV)	±(1% + 15mV)	±(1% + 15mV)
(2) (Matched input rise time)	2.5ns/3Vp-p	2ns/3V			3ns/3V	3ns/3V	3ns/3Vp-p	3 ns/3 Vp-p
(3) Input capacitance	64~72	35	50	35	35	35	25	35

Table 2. Relation Between Test Cost and System Architecture

Type of cost	Item to be considered	Description (Notes)
1. Test system introduction cost	Cost of purchasing test system	∘Change in the yen-to-dollar exchange rate
2. Test system operation cost	Power consumption	
	Installed area	∘Space for connection to the handler/prober ∘Space for maintenance work
	Cost for repair	∘Including MTBF/MTTR
	Operating ratio	∘Number of different items (general purpose) to be tested
	Set-up efficiency	∘Ease of system set-up at the mass production line ∘Ease of operation in changing test items
3. Item to be considered	Time and cost for the development of test modification tools	∘Necessary functions of peripheral circuit for the test and its extent
4. Development cost for test program	Time and cost for test program development	∘Use of high-level programming language ∘Ease of programming process ∘Linking capability to CAD system ∘Program compatibility with other systems
5. Cost for test pattern development	Efficiency for faction pattern development	∘Linking capability to CAD system
6. Cost for mass production test	Through-put	∘Data log, histogram, summary sheet
	Yield variation	∘Measurement precision (Calibration function)
7. Cost for analysis of defects and quality control	Data processing, analysis functions	∘Data log, histogram, summary sheet ∘Correlation plot, wafer map, simulation plot
	Networking capability	∘Connectivity to other computer systems (EWS, host system

Table 3. Evaluation Items of Test Functions

Configuration	Test function	Evaluation items
1. Configured for multi-pin devices	Matrix, power supply Par pin measuring device	Pin count Par pin measuring source
2. Configured for linear/digital mixed mode devices	Digital pattern generation Digital signal processing technology (DSP)	Frequency, pin count, input/output level Application, expandability
3. High speed application	Test system hardware speed Computer control speed Multiplex function Parallel measurement function	Set-up time and control method of each hardware Localized control, and sharing of functions with the host system Number of multistations Technique for parallel processing
4. High precision application	High resolution Low system noise	Calibration system Noise level evaluation by means of well-defined standards
5. General purpose application	Availability to many options Devices to be tested R&D-to-mass production system integration Extent of needed peripheral circuits for the testing	Optional functions Extent of general purpose application Integration of testing package R&D Size reduction of circuit

Table 4. Examples of Linear IC Test System

Vendor	Model	Main application	Feature
Ando Electric	DIC8060	All linear ICs	Stacking, distribution system
Advantest	T3710 series	Digital/linear mix mode IC	Fast digital testing
	T3311	Fast DC test	Maximum 128 pins
	T3156	Image sensor	Real time video processing
	T7361	Flash converter	Maximum frequency 150 MHz
Shiba Measurement	WL-8000	All linear ICs	Private use high precision analog measurement
	WL-12	Limited application (dedicated tester)	Cost performance
Yokogawa Electric	S3520	All linear ICs	Distribution system, parallel processing
	S3520F	Flash converter	Low cost, high precision
Yokogawa Hewlett Packard	YHP9480	Digital/linear mix mode ICs	High precision, off-line debugging
LTX	LTX-77	All linear ICs	DSP technique may be incorporated; general purpose
	Hi-T	Digital/linear mixed mode IC	High through-put, DSP technique
Teradine	A340	DC, digital functions	Cost performance
	A360	All linear ICs	Low cost, general purpose
	A370	Image sensor Communication devices	Fast measurement by the use of vector-bus
	A500	Communication devices	DSP technology, high through-put

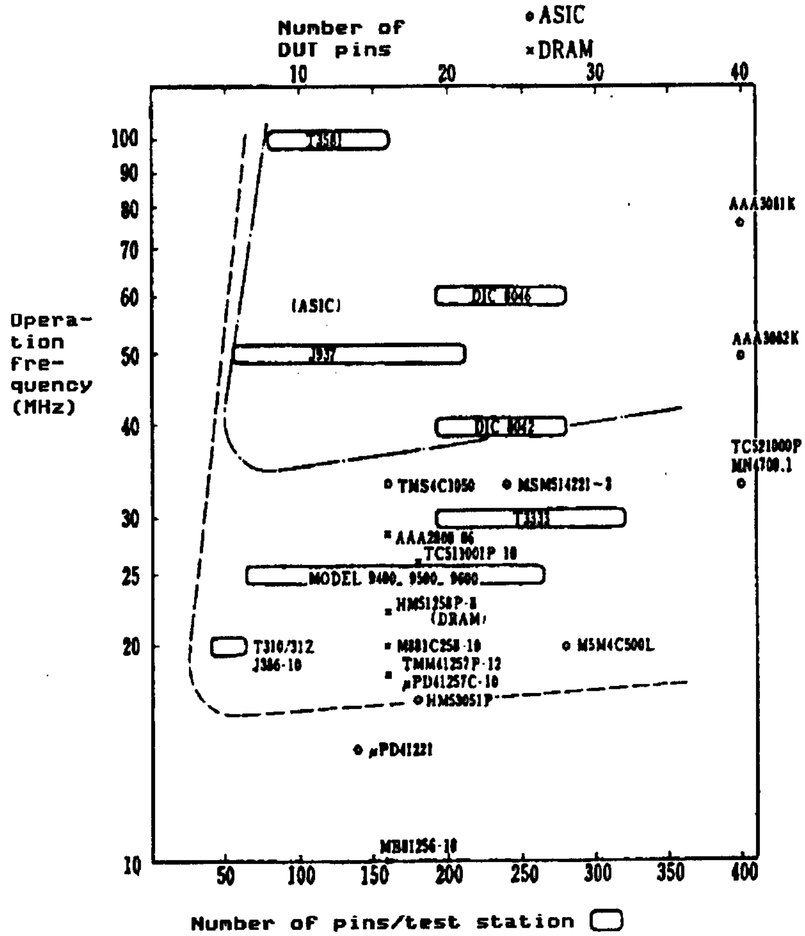

Figure 1. Classification of Memory ICs and Memory Testers According to the Frequency and Number of Pins

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